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ABSTRACT

This guide is Unit 2 of the four-part series, Science, Society, and America's Nuclear Waste, produced by the U.S. Department of Energy's Office of Civilian Radioactive Waste Management. The goal of this unit is to convey factual information relevant to radioactivity and radiation and relate that information both to the personal lives of students and to the management and disposal of nuclear waste. Particular attention is focused on the nature of ionizing radiation, radioactive decay, and half-life. The first section of Unit 2 includes four lesson plans about radiation detection, exposure, and half-life. The second section provides further background information and includes five lesson plans that explore the biological effects of ionizing radiation. Activity sheets for students and transparencies for the lesson plans and background notes are included in the third section followed by the unit test. Answers keys and a glossary are also included. Contains 17 references. (DDR)

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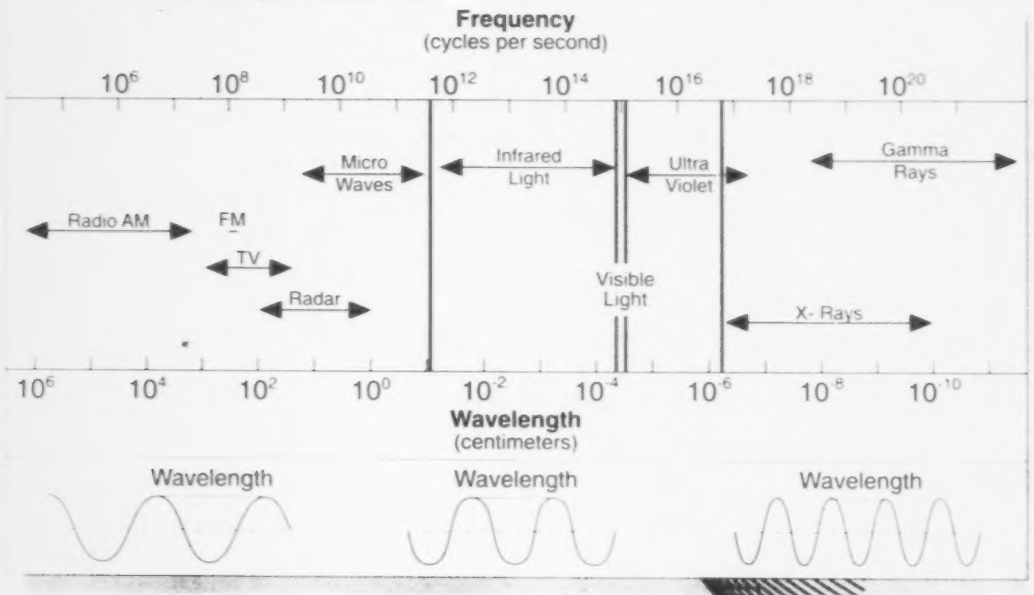
Science, Society, and America's Nuclear Waste



Ionizing Radiation

Unit 2 Second Edition
Teacher Guide

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"Science, Society and America's Nuclear Waste" is a four-unit secondary curriculum. It is intended to provide information about scientific and societal issues related to the management of spent nuclear fuel from generation of electricity at nuclear powerplants and high-level radioactive waste from U.S. national defense activities. The curriculum, supporting classroom activities, and teaching materials present a brief discussion of energy and electricity generation, including that produced at nuclear powerplants; information on sources, amounts, location, and characteristics of spent nuclear fuel and high-level radioactive waste; sources, types, and effects of radiation; U.S. policy for managing and disposing of spent nuclear fuel and high-level radioactive waste and what other countries are doing; and the components of the nuclear waste management system. The four units are:

Unit 1 - Nuclear Waste

Unit 2 - Ionizing Radiation

Unit 3 - The Nuclear Waste Policy Act

Unit 4 - The Waste Management System

In the study of nuclear waste management, or any other scientific and social subject, individuals are encouraged to seek differing perspectives and points of view.

This resource curriculum was produced by the U.S. Department of Energy's (DOE) Office of Civilian Radioactive Waste Management (OCRWM) and has been reviewed by selected staff, faculty, and/or workshop participants from: Louisiana State University; the University of Nevada, Reno and Las Vegas; the University of Tennessee; Pennsylvania State University; Hope College in Michigan; the University of South Florida School of Medicine; the New York State Department of Education, Science, Technology, and Society Education Project; the Nevada Science Project; the National Council for the Social Studies, Science and Society Committee; and the First International Workshop on Education in the Field of Radioactive Waste Management — At the Crossroads of Science, Society, and the Environment — co-sponsored by the multinational Organization for Economic Cooperation and Development/ Nuclear Energy Agency, U.S. Department of Energy's OCRWM, and the Swiss National Cooperative for the Storage of Radioactive Waste (NAGRA). The international workshop was attended by educators and information specialists from Austria, Belgium, Canada, Finland, France, Germany, Japan, the Netherlands, Spain, Sweden, Switzerland, the United Kingdom, and the United States. This curriculum was field tested through team-teaching by science and social studies teachers in Alabama, Florida, Georgia, Louisiana, Mississippi, South Carolina, and Texas.

For further information about this curriculum, please call 1-800-225-6972 (within Washington, DC, 202-488-6720) or write to:

OCRWM National Information Center
Attention: Curriculum Department
600 Maryland Ave., SW
Suite 760
Washington, DC 20024

The 1977 DOE Reorganization Act authorizes education and training activities necessary to ensure that the Nation has an adequate technical work force in energy-related research and production fields. These fields include mathematics, physics, geology, chemistry, zoology, biology, and other areas of basic and applied research. The DOE Science Enhancement Act (part of the 1991 National Defense Authorization Act) expands the Department's authorization to support science education and amends the 1977 legislation to make support for science education a major mission of the Department. Traditionally, the DOE educational emphasis has been on university-level education, with the agency providing graduate student fellowships and research appointments at DOE facilities. More recently, the education mission was expanded to include precollege education and science literacy.

DOE has been working diligently to make its contribution toward achieving our National Education Goals since their development following the 1989 Education Summit in Charlottesville, Virginia. Although DOE's work indirectly supports all the goals, DOE is especially involved in Goal # 4: "By the year 2000, U.S. students will be first in the world in science and mathematics achievement."

DOE sponsors a number of national and local energy education programs, in addition to this curriculum, through its national laboratories, energy technology centers, and various DOE program elements. For further information about these programs, please write to: U.S. Department of Energy, Office of Science Education and Technical Information, Washington, DC 20585.

Science, Society, and America's Nuclear Waste

Ionizing Radiation

Unit 2 Second Edition
Teacher Guide

July 1995

Department of Energy
Washington, DC 20585

To the Teacher:

This Second Edition of the Teacher Guide accompanies the resource curriculum *Science, Society, and America's Nuclear Waste*. The curriculum, produced by the United States Department of Energy's (DOE's) Office of Civilian Radioactive Waste Management (OCRWM), is designed to assist science and social studies teachers in presenting issues related to the safe management and disposal of America's nuclear waste. The curriculum was developed, reviewed, and tested by teachers for use in grades 8 through 12.

The *Science, Society, and America's Nuclear Waste* curriculum provides information and background on energy and waste-management issues. It is suitable for use in technology and environmental science classes and in social studies classes in middle, high school, and advanced lower grades. Its content and focus are consistent with national goals to strengthen and update math and science curriculum and broaden public science literacy.

Since the curriculum was first made available to the public in 1992, and as of August 1995, more than 20,000 Teacher Guides and approximately 200,000 Student Readers have been requested by and distributed to educators of diverse disciplines in all 50 States and in 48 foreign countries.

Ancillary materials, such as videotapes, a computer diskette, and other materials referenced in the document, may be obtained by calling the OCRWM National Information Center at 1-800-225-6972 (in Washington, D.C., 202-488-6720).

Sincerely,

E. J. Deshields

Evangeline Deshields, Manager
Office of Civilian Radioactive Waste Management
National Information Center

Printed with soy ink on recycled paper

Notice To Educators

These **Second Edition Teacher Guides** contain statistical updates that are current as of October 1, 1994. **First Edition Student Readers** are available upon request. Since very few statistical changes were required in the Student Readers, **Second Edition Student Readers** were not printed. Minor differences between the two editions are underlined in your Student Reader material contained in these Teacher Guides.

References to a Monitored Retrievable Storage (MRS) Facility and the Office of the Nuclear Waste Negotiator

You will note that throughout units 3 and 4 of the curriculum references are made to the concept of a Monitored Retrievable Storage (MRS) facility. The Nuclear Waste Policy Amendments Act of 1987 (the Act) authorized the siting, construction, and operation of such a storage facility as an integral part of the Federal waste management system. The Act gave the Secretary of Energy the authority to survey and evaluate sites for a storage facility then designate one. The Act also created the Office of the Nuclear Waste Negotiator to seek a State or Indian Tribe willing to volunteer a technically suitable site, under reasonable terms to be approved by Congress.

To counter a concern that interim central storage on the surface might become permanent, Congress linked the selection of a storage site to the recommendation of a repository site to the President by the Secretary. Under this limitation, construction of a storage site cannot begin until the Nuclear Regulatory Commission issues a license for construction of a repository. In 1989, the Department of Energy announced a delay in the recommendation of a repository site until 2001, and a delay in the expected date of repository operations until the year 2010. The Secretary also told Congress that if the linkage between the MRS facility and the repository were modified, then waste acceptance at the facility could begin by 1998. This was based on the assumption that a site would be available by then. However, the linkage remains in place, the Nuclear Waste Negotiator has not been able to find a volunteer candidate site, and accumulated political experience suggests that a volunteer site for interim storage is not likely. In the absence of interim central storage, waste acceptance and offsite transport could not occur until the start of repository operations in 2010.

The Fiscal Year 1995 budget does not provide funding to OCRWM for activities related to interim storage, and the statutory authority for the Office of the Nuclear Waste Negotiator expired in January 1995. However, references to an MRS facility are still included in the Second Revision, as the concept is still included in the Nuclear Waste Policy Act, as mentioned.

Because of the changes mentioned above, this edition's lesson in Unit 4, formally titled *The Role of the Monitored Retrievable Storage Facility*, has been replaced with the lesson *The Role of the Multi-Purpose Canister*. However, most of the other references to an MRS facility found throughout the curriculum have remained intact, most notably in Unit 3. Please take special note of this new information as you plan lessons around the concept of an MRS facility.

Please note that referenced videotapes and support materials can be obtained free of charge through the **OCRWM National Information Center at 1-800-225-6972 (in Washington, DC, 202-488-6720).**

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UNIT II: Ionizing Radiation

Lesson	Focus	Activities/Materials Provided	Content Area/ Grade Level
The Cloud Chamber (Core = 1 class period)	Illustrates that though radiation cannot be detected directly by using our senses, it is possible to observe the result of radioactive decay.	Discussion Questions Experiment • Reading Lesson • Discussion Questions • Activity Sheets (2)	Science (Grades 8-10)
Sources and Characteristics of Ionizing Radiation (Core = 2 class periods)	Introduces students to sources of ionizing radiation and helps put radiation associated with nuclear fuel activities in perspective.	Transparencies (4) Reading Lesson Activity Sheets (2) Discussion Questions Videotape (22 min.) Enrichments • Activity Sheets (4) • Reading Lesson (1)	Science (Grades 10-12)
Pennium-123 (Core = 1 class period)	Develops understanding that radioactive materials become less radioactive over time as a result of radioactive decay.	Activity Sheet Discussion Questions Enrichment • Charting Activity	Science (Grades 8-10)

UNIT II: Ionizing Radiation

Lesson	Focus	Activities/Materials Provided	Content Area/ Grade Level
Half-Lives (Core = 1 class period)	Reinforces that radioactive materials become less radioactive over time. Students learn that the half-life of a radioisotope is the time it takes for a quantity of that radioisotope to lose half of its radioactivity.	Activity Sheet Enrichment • Math Activity • Reading Lesson • Charting Activities	Math & Science (Grades 9-12)

IONIZING RADIATION

Unit Purpose:

This unit of study consists of a series of lessons and activities designed to convey factual information relevant to radioactivity and radiation and to relate that information both to the personal lives of students and to the management and disposal of nuclear waste.

Students will experiment and determine that although radiation cannot be detected with the senses, it is possible to study radiation through indirect observation. The concept that ionizing radiation is a part of nature and our natural environment, but can result from human activity as well, will be introduced. Radioactive decay and half-life will be studied in depth to facilitate understanding of plans for permanent disposal of radioactive wastes that will continue to emit radiation for hundreds of thousands of years. This understanding will help students develop an appreciation for the necessity of planning carefully for disposal of these wastes.

Unit Concepts:

Nuclear waste emits radiation. Radiation cannot be detected directly by the senses. Nuclear waste becomes less radioactive over time.

1. Radiation cannot be detected directly by using our senses.
2. Ionizing radiation is energy in the form of electromagnetic waves (X-rays and gamma rays) or fast-moving particles (alpha and beta particles).
3. Ionizing radiation is part of our natural environment but can also result from human activities.
4. Ionizing radiation from natural sources contributes more than 80 percent of the the average exposure of an individual residing in the United States.
5. Radioactive materials become less radioactive over time through the process of radioactive decay.
6. Radioactive decay curves may be illustrated by graphing the flipping of a coin.
7. The time for radioactive materials to lose essentially all of their radioactivity can vary from seconds to thousands of years.
8. Radioactive materials with the highest activities per unit weight decay the fastest.
9. Each radioactive isotope has its own distinct half-life.

Duration of Unit:

Five 50-minute class periods

Unit Objectives:

As a result of participation in this unit of study, the learner will be able to:

1. discuss a cloud chamber demonstration;
2. define ionizing radiation;

3. name both natural and manmade sources of ionizing radiation;
4. state how many millirem of exposure to radiation the average American receives annually;
5. state what percentage of exposure of the average American to ionizing radiation is from natural sources;
6. state approximately how many millirem of exposure to ionizing radiation he/she personally received this year;
7. name the sources of his/her personal exposure;
8. collect, chart and graph data;
9. complete a chart on half-lives of significant radioisotopes;
10. differentiate which three radioisotopes have the highest and lowest specific activity; and
11. explain the significance of the information on the half-life chart as it relates to permanently disposing of radioactive wastes.

Unit Skills:

Analyzing, calculating, collecting and organizing data, critical thinking, deductive reasoning, drawing conclusions, evaluating, filling in a chart, interpreting, measuring, note-taking, observing, plotting data on a graph, reading, reading and interpreting graphs and tables, working in groups.

Unit Vocabulary:

Acute exposure, alpha particle, background radiation, beta particle, cancer, cosmic radiation, decay product, distribution of risk, electromagnetic spectrum, electron, erg, fission, frequency, gamma ray, genetic effect, half-life, ion, ionization, ionizing radiation, isotope, kilogram, millirem, nuclear fuel cycle, radiation, radioactive decay, radioisotope, radon, rem, spent fuel, terrestrial radiation, transuranic, uranium, X-ray.

Unit Materials:

Reading Lesson
Ionizing Radiation Sources and Exposures, p. SR-1

Activity Sheets
The Cloud Chamber, p. 87
Ionizing Radiation Exposure in the United States, p. 101
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Videotape

Radiation: Fact and Myth **(available free of charge from the OCRWM National Information Center, 1-800-225-6972; within Washington, DC, 488-6720)**

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Other

Demonstration/experiment supplies (See individual activity sheets.)

INTRODUCTION

Radiation

Radiation is perhaps easiest to understand when you remember that it is energy moving through space in the form of waves and particles. Radiation is everywhere — in, around, and above the world we live in. We could think of it as a natural energy force that surrounds us. We are generally not very aware of it until we are reminded of it by someone or something, like a reflector on a bicycle, a full moon, or listening to a favorite radio program.

Types of Radiation

Depending on how much energy it has, radiation can be described as either *non-ionizing* (low energy) or *ionizing* (high energy).

Non-Ionizing Radiation

All our lives, perhaps without knowing it, we have reaped the benefits associated with non-ionizing radiation. For example, radio and television waves provide news and entertainment in the home, microwaves ease some cooking tasks, the light from electric light bulbs takes away the night, and the ultraviolet light from grow lights brings an artificial sun indoors for our flowering plants. These are some forms of non-ionizing radiation.

Ionizing Radiation

High-energy ionizing radiation is called ionizing because it can knock electrons out of atoms and molecules, creating electrically charged particles called *ions*. Material that ionizing radiation passes through absorbs energy from the radiation mainly through this process of *ionization*.

Ionizing radiation can be used for many beneficial purposes, but it also can cause serious, negative health effects. That is why it is one of the most thoroughly studied subjects in modern science. Most of our attention in this section will be focused on ionizing radiation — what is it, where it comes from, and some of its properties.

THE CLOUD CHAMBER

Purpose:

The Cloud Chamber experiment illustrates that though radiation cannot be detected with the senses, it is possible to observe the result of radioactive decay.

Concepts:

1. Radiation cannot be detected directly by using our senses.

Duration of Lesson:

One 50-minute class period.

Objectives:

As a result of participation in the Cloud Chamber experiment, the learner will be able to:

1. describe that as charged particles pass through the chamber, they leave an observable track much like the vapor trail of a jet plane; and
2. conclude that what he/she has observed is the result of radioactive decay.

Optional Objectives:

1. Through measurement of tracks in the Cloud Chamber, the learner will be able to determine which type of radiation travels farthest from its source.
2. By holding a strong magnet next to the Cloud Chamber, the learner will be able to deduce what effect, if any, a magnet has on radiation.
3. By wrapping the source alternately in paper, aluminum foil, plastic wrap and then cloth, the learner will be able to conclude what effect, if any, shielding has on radiation.

Skills:

Drawing conclusions, measuring, note-taking, observing, deductive reasoning, working in groups

Vocabulary:

Alpha particle, beta particle, gamma ray

Materials:

Activity Sheets

The Cloud Chamber, p. 87

Background Notes

Safe Use of Dry Ice, p. 5

Cloud Chamber, p. 5

Suggested Procedure:

1. It is suggested that students work in groups no larger than three or four in order to derive maximum benefit from this experiment. Students should be prepared to take notes of their observations as the experiment progresses.
2. Prepare cloud chamber as directed on activity sheet.
3. Most of the tracks will be about 1/2 inch long and quite sharp. Explain that these are made by alpha radiation.
4. Sometimes you will see longer, thinner tracks. Tell students that these are made by beta radiation.
5. Occasionally, you may see some twisting, circling tracks that are so faint they are difficult to see. Tell students these are caused by gamma radiation.

Sample Discussion Questions:

1. You could not actually see the radiation. What kind of observation did you experience?
   (Indirect observation)
2. What is actually happening to the radioactive source?
   (The radioactive source is decaying.)
3. What radiation "footprints" did you see? Describe them.
   (Answers will vary. See descriptions on activity sheet.)

Teacher Evaluation of Learner Performance:

Learner notes of observations taken as the Cloud Chamber activities progress may be collected and used to determine degree of comprehension.

Learner response to questions/participation in discussion as the experiment progresses will indicate comprehension.

Enrichment:

Atoms and Isotope Review, p. SR-17, 109
Chemical Element Worktable, p. 117

Additional Enrichment:

The following are additional experiments that can be done with a Cloud Chamber:

Experiment A: How far can radiation travel?

Carefully mark the top of the jar at the point where the alpha tracks disappear. Measure how far the radiation travelled from the source. Then measure the beta tracks. Which type of radiation travelled farthest from the source?

Experiment B: Does a magnet affect radiation?

Hold the north end of a strong magnet next to the jar. Do you see any effect on the alpha tracks? On the beta?

Experiment C: How does shielding affect radiation?

Wrap the source in a sheet of paper. Which types of radiation are still visible?

Wrap the sample in a sheet of aluminum foil. Is the effect the same?

What happens if you use plastic wrap or cloth?

What types of radiation are stopped by each material?

(Be sure to allow time to cool the jar after each time it is opened.)

If you have access to a Geiger counter, students can test various items to see if they are radioactive. Materials that can be used include luminous clock dials from old clocks, "lite" salt (potassium chloride), some clothing jewelry, orange-glazed Fiestaware dishes, and smoke detectors. Students can also test the background radiation present in the classroom.

SAFE USE OF DRY ICE

Caution: Dry ice must be handled with care.

1. Dry ice must not be tasted, placed near the mouth or allowed to touch the skin, as the extremely low temperature could cause a burn.

2. Dry ice must not be placed in glass jars, bottles, or tightly sealed containers. They could explode due to the high pressure.

3. Do not breathe the gas from dry ice for an extended period in a closed area, such as a car. Store the dry ice in a container such as a styrofoam cooler until you are ready to use it.

4. When the dry ice has served its purpose and you no longer have any use for it, open the container and let the dry ice dissipate in a safe place, preferably outside where students or others will not find it and play with it.

CLOUD CHAMBER

Source Of Materials

Science supply houses have plastic containers for cloud chambers. They may also have sources that can be used. (Gas lantern mantles may be used, but they do not work as well as commercial sources, luminous dials, or uranium ore.)

Dry ice can be purchased where fire extinguishers are recharged. A CO_2 fire extinguisher can also be used. (Shooting the fire extinguisher into a burlap bag helps to reduce mess.) Additionally, dry ice may be found at many ice suppliers listed in the "Yellow Pages" of your telephone directory. Ethyl alcohol can usually be purchased where liquor is sold.

A possible source of a Geiger counter is your local civil defense or emergency response officer, a local utility, a college or university, a firehall, or hospital radiology lab.

What To Look For

The air layer near the bottom of the jar is supersaturated with alcohol vapor. (There is more vapor in the air than is usual at the low temperature and as a result, the gas will form liquid droplets whenever it is disturbed.) Dust in the jar will cause the alcohol to condense into small droplets, which you can see as a fine mist falling to the bottom of the jar during the first half hour that you are using the chamber. After a while, however, most of the dust will have fallen to the bottom of the dish and the mist will disappear.

The tracks formed by the radiation appear to be white lines in the cloud. As the radiation passes through, it knocks electrons out of the atoms in the air. The alcohol vapor then condenses on the charged particles, forming little "storms" along the path. These tracks disappear almost immediately.

Students may be able to find three kinds of tracks. (See activity sheet.)

After a while the tracks will become faint because the radiation has affected so many of the atoms in the jar. When this happens, rub the top of the jar briskly with the cotton or silk cloth. The static electricity that is produced will clear the jar and cause the tracks to become visible again.

THE CLOUD CHAMBER

Three important forms of ionizing radiation are alpha and beta particles and gamma rays. Alpha particles are identical to the nucleus of a helium atom. They have a double positive charge (two protons) and are relatively large. Beta particles are much smaller. They carry a single negative charge (one electron). Gamma rays have no mass or charge.

Ionizing radiation cannot be detected using our senses. However, a cloud chamber allows you to see the tracks it leaves in a dense gas. When charged particles pass through the chamber, they leave a track much like the vapor trail of a jet plane.

PURPOSE:

What is the purpose of this activity?

(The purpose of this activity is to make indirect observations of radiation.)

HYPOTHESIS:

Directions: Draw a picture of what you expect the radiation tracks to look like. Remember that there are three types of radiation: alpha and beta particles and gamma rays.

(Drawings will vary.)

MATERIALS:

small transparent container with transparent, tight-fitting lid (such as refrigerator jar or cloud chamber purchased from scientific supply company)

flat black spray paint

blotter paper (one strip about 5 centimeters [2 inches] wide and long enough to fit around the inside of the jar)

cotton or silk cloth

ethyl alcohol

source (uranium ore, numeral from a luminous dial, purchased source, etc.)

masking tape

"dry ice"

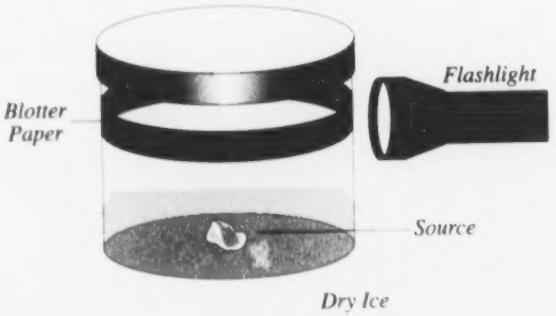
tongs or gloves for handling dry ice

flashlight

CAUTION: DO NOT HANDLE DRY ICE WITH YOUR BARE HANDS. USE TONGS OR GLOVES.

PROCEDURE:

1. Paint the bottom of the jar with the black paint. Allow the paint to dry.
2. Attach the blotter paper to the inside of the jar near the top. You may need to tape it.
3. Pour a very thin layer of ethyl alcohol on the bottom of the jar.
4. Soak the blotting paper ring with alcohol.
5. Place the radiation source on the bottom of the jar and put the lid on tightly. Tape around the lid.



6. Place the jar on top of the dry ice.
7. Allow the jar to super cool for 5 minutes.
8. Darken the room and shine the flashlight through the side of the jar. Through the top, you should see white lines or "tracks" inside the jar close to the bottom.
9. You may be able to find three kinds of tracks:
   a. Most of the tracks will be about 1.3 centimeters (0.5 inch) long and quite sharp. These are made by alpha radiation.
   b. Sometimes you will see longer, thinner tracks. These are made by beta radiation.
   c. Occasionally, you may see some twisting, circling tracks that are so faint that they are difficult to see. These are caused by gamma radiation.

OBSERVATIONS:

Directions: Draw and label pictures of what you see in the cloud chamber.

CONCLUSION:

1. Were you able to observe radiation directly or indirectly in the cloud chamber?

   (Radiation can only be observed indirectly.)

2. Write a concluding statement explaining how we know radiation exists.

   (We know that radiation exists through indirect observations like using Geiger counters, radiographs, or in cloud chambers.)

IONIZING RADIATION: SOURCES AND EXPOSURES

Purpose:

This lesson will introduce students to sources of ionizing radiation and explain how much exposure the average U.S. citizen receives from various sources annually. The lesson will help students put radiation associated with nuclear fuel cycle activities (i.e., all those steps associated with generating electricity at nuclear powerplants, from mining to waste disposal) in perspective.

Concepts:

1. Ionizing radiation is energy in the form of electromagnetic waves or fast-moving particles.
2. Ionizing radiation is part of our natural environment but also can result from human activities.
3. Ionizing radiation from natural sources contributes more than 80 percent to the average exposure of 360 millirem of an individual residing in the United States.

Duration of Lesson:

Two 50-minute class periods

Objectives:

As a result of participation in this lesson, the learner will be able to:

1. define ionizing radiation;
2. name both natural and manmade sources of ionizing radiation;
3. state how many millirem of exposure to radiation the average American receives annually;
4. state what percentage of exposure of the average American to ionizing radiation is from natural sources;
5. state approximately how many millirem of exposure to ionizing radiation he/she personally received this year; and
6. name the sources of his/her personal exposure.

Skills:

Calculating, reading, reading and interpreting graphs and tables

Vocabulary:

Acute exposure, alpha particle, background radiation, beta particle, cancer, cosmic radiation, decay product, electromagnetic spectrum, electron, erg, frequency, gamma ray, genetic effect, ion, ionization, ionizing radiation, millirem, nuclear fuel cycle, radiation, radioactive decay, radioisotope, radon, rem, terrestrial radiation, uranium, X-ray

Materials:

Reading Lesson

Ionizing Radiation: Sources and Exposures, p. SR-1

Activity Sheets

Ionizing Radiation Exposure in the United States, p. 101

Calculating Your Personal Radiation Exposure, p. 103

Transparencies

DNA Molecule, p. 91

Cancer Risk Versus Radiation Exposure, p. 93

Radiation Exposure Pathways, p. 95

Electromagnetic Spectrum, p. 97

Radiation Paths in Tissue, p. 99

Videotape

Radiation: Fact and Myth, 22 minutes **(available free of charge from the OCRWM National Information Center, 1-800-225-6972; within Washington DC, 488-6720)**

Background Notes

Radiation Exposure, p. 16

Suggested Procedure:

1. You may want to introduce this topic by showing the videotape entitled *Radiation: Fact and Myth.* It might be wise for students to take notes as they view the film to facilitate discussion of the video's key themes.

Sample videotape questions - *Radiation: Fact and Myth*

a.) What happens during radioactive decay?

b.) How is ionizing radiation different from other radiation?

c.) How can we detect radiation?

d.) What is the most penetrating type of ionizing radiation? the least penetrating?

e.) How can we reduce our exposure to radiation?

f.) What are some sources of radiation?

g.) What are some uses of radiation?

h.) What are some concerns about radiation?

2. The vocabulary introduced in this lesson is extensive. Depending on the group, it might be helpful to preview vocabulary before beginning the reading lesson.
3. Assign the reading entitled *Ionizing Radiation: Sources and Exposures.* Before students begin, briefly preview the reading by going over the questions in the margins to focus their attention on the topics that will be covered. Allow students 30 minutes to complete the reading, and then discuss it.
4. Assign the reading review entitled *Ionizing Radiation Exposure in the United States.* When the students have completed the review exercises, you may use the sample discussions questions below for class discussion. Following the class discussion have students complete *Calculating Your Personal Radiation Exposure.*

Sample Discussion Questions:

1. What is ionizing radiation? What are some important forms of ionizing radiation?

   (Ionizing radiation is high-energy radiation that has the ability to knock electrons out of atoms and molecules, creating charged particles called ions.

   Some important forms of ionizing radiation are cosmic rays, the X-rays produced by X-ray machines, and the alpha and beta particles and gamma rays and X-rays emitted by radioactive materials.)

2. All electromagnetic radiation (e.g., radio and television waves, microwaves, visible light, X-rays, gamma rays, etc.) travels at the speed of light. Looking at the electromagnetic spectrum, what property appears to determine whether electromagnetic radiation is non-ionizing or ionizing?

   (As you proceed across the spectrum from left to right, the frequency, in cycles per second, of the electromagnetic radiation increases and the radiation becomes higher in energy.

   NOTE: As the frequency increases, the wavelength—the distance covered by one cycle—decreases. The wavelength is equal to the velocity of light divided by the frequency.)

3. Discuss the various pathways by which people are exposed to ionizing radiation in everyday living.

   (Pathways of exposure are shown in the figure "Radiation Exposure Pathways." Pathways illustrated include cosmic radiation, indoor air and structural radiation, airborne radioactive pollutants, or dissolved radioactive pollutants. Cosmic radiation can reach people directly. Indoor air contains radon. Structural radiation refers to radiation from building materials, like bricks, that are made of materials that contain radioactive materials. Airborne or dissolved pollutants can reach people through the food chain or directly through inhalation or ingestion.)

4. The average American is exposed to about 360 millirem of ionizing radiation per year. Discuss the various sources and the amounts they contribute, in millirem, and in terms of the percentage of the total exposure.

   (The table of exposures and the pie chart of percentages can supply information for a good discussion. The discussion can be tied in with the reading reviews and the personal exposure chart students can complete. It may be interesting to ask students whether the percentages are surprising to them or what they expected.)

5. Radon, a naturally occurring radioactive gas, contributes a significant percentage to the average individual's annual exposure to ionizing radiation. If your family tested your home and discovered unacceptable levels of radon present, what could you do to reduce your family's exposure?

   (Increase ventilation in the house, especially in the basement.)

6. Some of the foods we eat contain radioactive isotopes. Should we be concerned and take care to avoid these foods? Why or why not?

   (No. To function properly, our bodies require potassium, a main source of our internal exposure to ionizing radiation.)

7. Our bodies can usually repair damage associated with low exposures to ionizing radiation comparable to the radiation we receive from natural sources or ordinary medical X-rays. Why then are we concerned with minimizing exposures to even these small exposures?

   (Many things cause cancer or genetic effects. These effects cannot be distinguished from those cause by radiation. A burn from radiation, for instance, looks like any other burn. We cannot prove that there is no negative health effect from low exposures. Therefore, some small risk is assumed for even low levels of exposure.)

8. Alpha particles can be stopped by a sheet of paper and beta particles by a thin aluminum metal. Gamma rays and X-rays deposit much less energy per unit path in human tissue than the particles. Why, then, is it necessary to store and ship spent fuel in heavy shielded casks?

   (While individual gamma rays or X-rays deposit only small amounts of energy along their path, the very large number of rays coming from spent fuel are such that their many intersecting paths in human tissue create localized areas of ionization that cause severe biological damage. Therefore, the shielded casks are necessary to reduce exposure to radiation from the spent fuel to acceptable levels.)

9. It is easier to detect the presence of radioactive materials than it is to detect the presence of other hazardous materials. Why is this important in waste management and disposal?

   (The presence of most hazardous materials must be detected chemically. To do this, you need more of the hazardous material than you would need to detect a radioactive substance. The procedures and equipment for chemical identification are more suitable for the laboratory than the field. Radiation detection instruments can not only detect extremely small quantities of radioactive materials, but they are also ideal for use as monitors in the field. These factors improve safety by enabling us to monitor readily.)

Teacher Evaluation of Learner Performance:

Student participation in class discussions and completion of the reading review entitled *Ionizing Radiation Exposure in the United States* and the activity *Calculating Your Personal Radiation Exposure* will indicate understanding.

Enrichment:

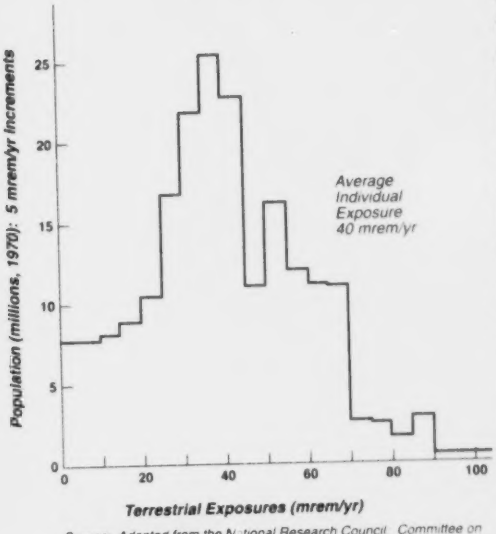
Radioactivity in Food, p. 119
Jet Flight Exposure, p. 123
Cosmic Radiation, p. 125
Apollo Flight Exposure, p. 127
Manmade Radiation Sources, p. 129
Biological Effects of Ionizing Radiation, pp. SR-21, 131

Radiation is a subject many students may be concerned about. Either after this lesson or after students have completed the enrichment lesson entitled *Biological Effects of Ionizing Radiation*, arrange for someone in the community who works with radioactive materials to come to speak to the class. Your local hospital, a university or college, or a utility that operates a nuclear powerplant are all good sources for speakers. Students can prepare for a speaker by writing questions about radiation that they would like to have answered. The questions can either be submitted to the speaker in advance or can be asked at the time of the visit.

RADIATION EXPOSURE

The ways in which our everyday exposures to ionizing radiation are handled in the section entitled *Ionizing Radiation: Sources and Exposures* requires some explanation. The principal source of information in this section is the National Council on Radiation Protection and Measurement's (NCRP's) *Report No. 93, Ionizing Radiation Exposure of the Population of the United States*, but other important sources of information have also been consulted and appear in the reference list of the section on biological effects. One very important reference on natural radiation exposure not in that list but used by definitive sources on the subject is a doctoral thesis performed under the auspices of the U. S. Environmental Protection Agency by D. T. Oakley at Harvard University, *Natural Radiation Exposure in the United States, EPA Report ORP/SID 7201*, Washington, DC, 1972. According to Oakley, the average individual exposure from terrestrial radiation in the mainland United States, not corrected for self-shielding, is 40 mrem per year (see figure at left).

MAINLAND U.S. POPULATION DISTRIBUTION VERSUS ANNUAL TERRESTRIAL RADIATION EXPOSURE



Source: Adapted from the National Research Council Committee on the Biological Effects of Ionizing Radiation (BEIR III) The Effects on Populations of Exposure to Low Levels of Ionizing Radiation, 1980

To obtain the average exposures, natural sources of ionizing radiation are handled in a variety of ways. Cosmic radiation is usually reduced by 10% to account for building shielding and to account for the fact that people spend a lot of time in buildings. Average terrestrial radiation in *NCRP Report No. 93* is 28 mrem/yr, reduced by 30% from 40 mrem/yr to take into account body self-shielding. It is also assumed that exposure to terrestrial shielding is the same outside and inside buildings. (In *The Effects on Populations of Exposure to Low Levels of Ionizing Radiation*, The National Research Council Committee on the Biological Effects of Ionizing Radiation, BEIR III, assumes a 20% reduction for building shielding and an additional 20% for body self-shielding.) The 200 mrem per year individual exposure attributed to radon requires a special explanation. The part of the body exposed to radon and its decay products is, of course, the upper part of the respiratory system, and the 200 mrem for radon in the table and represented in the pie chart is a whole-body exposure. It is estimated by the NCRP that a 200 mrem whole-body exposure poses the same health risk to the body (i.e., the same risk of a fatal cancer) as that posed by actual exposure of the upper respiratory system to radon and its decay products.

Similarly, for inclusion in the exposure table, where only a part of the body is exposed, a whole-body exposure giving the same cancer risk as the actual exposure is the number used. For example, the numbers given for the various exposures to manmade radiation sources are real or calculated whole-body exposures.

The number given for the average annual exposure to building materials (i.e., the buildings we live and work in) is 7 mrem. Definitive information that differentiates the exposures from stone, brick, and wood houses is not available. The data on exposures from building materials are fragmentary, widely scattered and sometimes contradictory. Estimates of building exposure are further complicated by the use of gypsum board that contains radioactive elements of the uranium and thorium series. A definitive study on exposures from building materials, of the stature of Oakley's thesis on terrestrial radiation exposure, would appear to be very desirable.

IONIZING RADIATION: SOURCES AND EXPOSURES

We are constantly exposed to ionizing radiation. It is in the air we breathe and in the things around us. It reaches us from outer space. It also is used extensively in medical diagnosis and treatment. It is part of our lives.

2.1 Ionizing Radiation

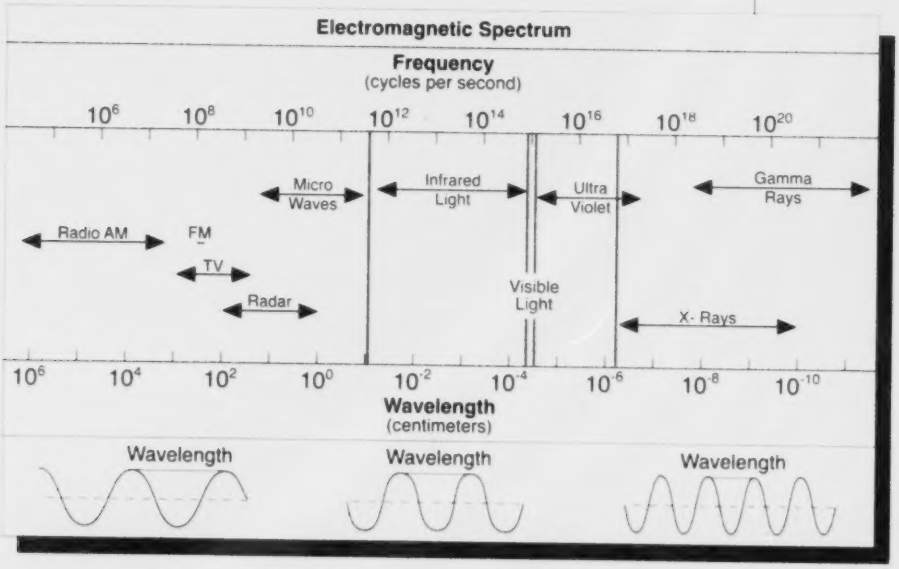
What are some forms of ionizing radiation?

Some important forms of ionizing radiation are the *alpha* and *beta particles*, *gamma rays*, and *X-rays* emitted from radioactive materials. The *cosmic radiation* that reaches the Earth from outer space is also ionizing. Ionizing radiation, in the form of X-rays, is produced by X-ray machines.

What are gamma rays and X-rays?

Gamma rays and X-rays are waves of pure energy, without mass or charge. They are ionizing. They appear at the high frequency (high energy) end of what we call the *electromagnetic spectrum* shown below. The various non-ionizing radiations (radio and television waves, microwaves, light, etc.) occupy the lower frequency (lower energy) part of the electromagnetic spectrum.

What is the electromagnetic spectrum?



The gamma rays and X-rays emitted by radioactive materials are waves of pure energy. Like all electromagnetic waves, they travel at the speed of light and their energies are determined by their frequencies. Alpha and beta particles are not part of the electromagnetic spectrum. They travel at much less than the speed of light and their energies are functions of their velocities and masses.

SR-1

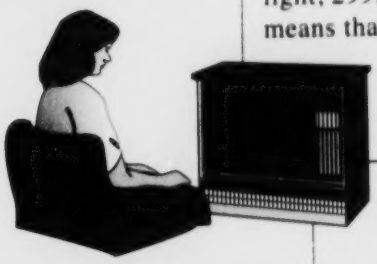
How fast does electromagnetic radiation travel? What determines its energy?

All types of electromagnetic radiation, ionizing and non-ionizing, travel at the speed of light. Their energies are not determined by their speed (the speed of light) but by their frequencies, the number of waves or cycles per second. (Alpha and beta particles are **not** part of the electromagnetic spectrum. They travel at very fast rates but slower than the speed of light.)

How is electromagnetic radiation important in your life?

The Speed of Light

It may not have occurred to you that all electromagnetic radiation travels at the speed of light and has an immediate bearing on your life. Radio and television waves travel at the speed of light, 299,274 kilometers (186,000 miles) per second. That means that a live broadcast you may be listening to or looking at on TV (from the other side of the world) is actually happening at the very second you are hearing or seeing it. If such signals had to circle the Earth, they would circle the Earth seven times every second.



2.2 Radiation Injury

How do the types of ionizing radiation differ?

Because it can knock electrons from the atoms and molecules in its path, ionizing radiation can cause chemical and/or physical changes in human tissue. However, the various types of ionizing radiation differ widely in their abilities to penetrate tissue and deposit energy through ionization.

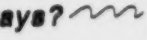
What are some properties of alpha particles?

Alpha particles, for instance, are relatively large and carry a double positive charge. They are not very penetrating and can be stopped by a piece of paper. They travel extremely short distances in human tissue but deposit all their energies along their short paths, doing a relatively large amount of damage.

What are some properties of beta particles?

Beta particles (electrons) are extremely small compared to alpha particles and carry a single negative charge. They are more penetrating than alpha particles, but can be stopped by thin aluminum metal. They travel much longer distances in human tissue and deposit much less energy along their paths.

What are some properties of gamma rays and X-rays?



Gamma rays and X-rays, having no mass or electrical charge, can travel extremely long distances in human tissue compared to particle radiation (alpha and beta). They deposit much less energy along their paths, but can damage internal organs.

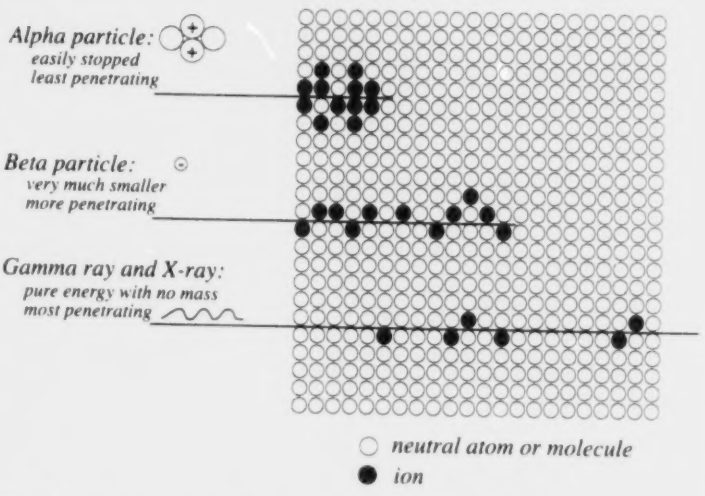
Measuring Potential Health Effects of Ionizing Radiation

The basic unit for measuring radiation received is the *rad* (radiation absorbed dose). One rad equals the absorption of 100 ergs[1] in every gram of tissue exposed to radiation.

To show biological risk, rads are converted to *rems*. The rem (radiation equivalent man) is adjusted to take into account the type of radiation absorbed and the likelihood of damage from the different types of radiation. Exposures are normally in fractions of a rem, so the commonly used unit of exposure is the *millirem* (*mrem*).

1 rem = 1000 millirem

[1]erg—a small but measurable amount of energy (See Glossary)



This drawing shows what the "paths" of different types of radiation might look like. Ions are formed when a particle, gamma ray, or X-ray penetrates tissue. Because alpha particles deposit all their energy along a short path, they are more likely to cause damage.

Source: Adapted from Radiation Activities for Youth Series, *copyright The Pennsylvania State University, Nuclear Engineering Department, 1988. Permission for use granted.*

How is ionizing radiation measured?
What is a rad?
What is a rem?
What is a millirem?

Acute Exposures

The effect of radiation on the body depends mostly on how long the exposure lasted, how much energy was absorbed, and the type and number of cells that were affected. Scientists have data about high exposures received in a short time and generally agree on the effects. For instance, radiation exposures of over 100,000 millirem usually cause radiation sickness. Exposures of over 500,000 millirem received in just a few days will usually result in death. Fortunately, such *acute exposures* are extremely unusual.

What does the effect of radiation depend on?

What are some effects of acute exposures?

Low Exposures

Very little reliable information is available about the effects of human exposure to low doses of radiation. As a result, different theories predict different effects for low exposures.

Do scientists agree about the effects of radiation?

There is disagreement among scientists about the risk of harm from exposure to low levels of ionizing radiation. A minority of scientists believe that low levels of radiation have a relatively high risk of a harmful effect. However, most scientists believe that low levels of radiation have an extremely low risk of a harmful effect on health.

Can the body repair changes caused by radiation?

Our bodies can usually repair cell damage that occurs naturally. Therefore, if radiation exposure is low, or the radiation is received over a long period of time, the body can usually repair itself. However, the body sometimes may repair damage incorrectly. As the incorrectly repaired cells divide and form new cells, the new cells carry the incorrect repair. There is then a possibility of a harmful effect that is delayed and does not show up for many years. It is also possible that there will be no harmful effect. Two types of possible delayed effects are cancer and genetic defects.

What is the possibility of a delayed effect?

Why is it hard to determine the effect of exposure to low levels of ionizing radiation?

Many things can cause cancer or genetic defects. These effects cannot be distinguished from those caused by radiation. So, it is very hard to determine exactly the effects of exposure to low levels of ionizing radiation.

Minimizing Risk

Why is some risk assumed for even small exposures?

Because we cannot prove that there is no effect, some risk is assumed for even small exposures. Therefore, it is important to know the sources of ionizing radiation and to avoid unnecessary exposure.

2.3 Sources of Ionizing Radiation

Natural Background Radiation

Ionizing radiation sources include both natural and manmade sources. The main natural sources are cosmic radiation, the rocks and soils around us, radon and its decay products in the atmosphere, and the radioactive materials in our bodies. The radiation from rocks and soil is often referred to as *terrestrial* radiation. The sum of the exposures from cosmic radiation, terrestrial radiation, and the radiation from the atmosphere is called *background radiation.*

What are some natural sources?

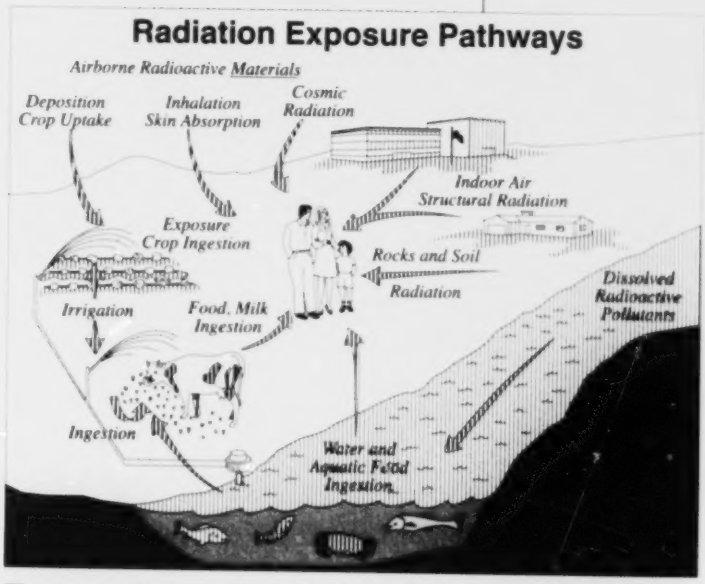
What is terrestrial radiation?

What is background radiation?

Manmade Radiation

The main sources of manmade radiation are the X-rays and the radioactive isotopes (radioisotopes) used in medical practice. Other manmade sources include nuclear industry facilities and consumer products, such as lantern mantles used for camping. Still other manmade sources are those related to technology. One example is ash from coal-fired powerplants that contains the radioactivity originally present in the coal, but in more concentrated form. Other examples are increased terrestrial radiation from disturbing earth during construction and road building, and fertilizers made from phosphates.

What are some manmade sources?



There are a variety of pathways by which people are exposed to ionizing radiation. Cosmic radiation, immersion in and inhalation of indoor and outdoor air, exposure to radiation from rocks and soil, and ingestion of food and drink are most important.

How much radiation is the average American exposed to per year from all sources?

2.4 Ionizing Radiation Exposures

The average American is exposed to about 360 millirem of ionizing radiation per year. This average exposure comes from all sources, including radon and medical exposures.

Ionizing Radiation Exposure in the United States

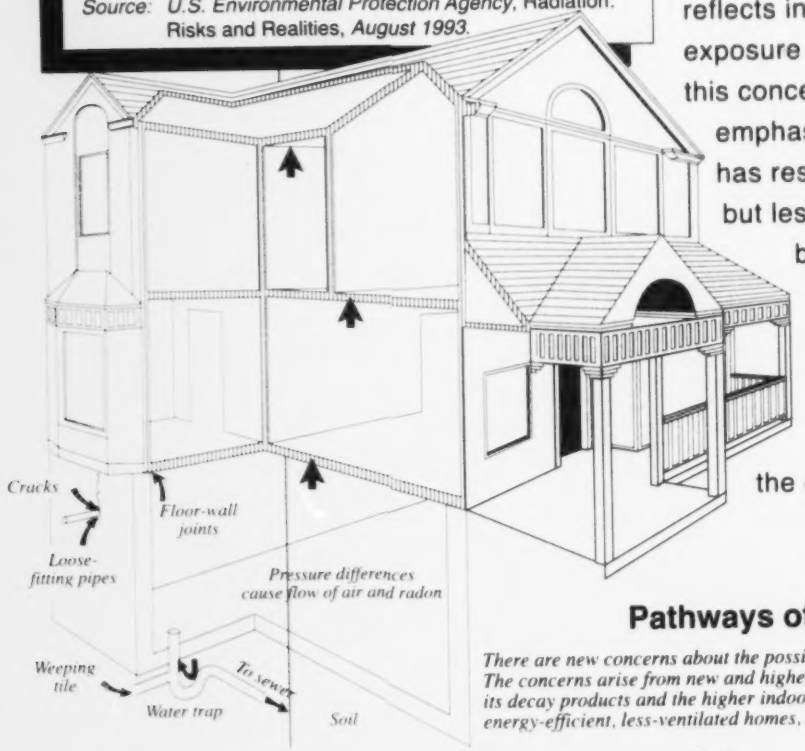
Source	Estimated average annual whole-body exposure (millirem)
Natural:	
Radon	200
Internal radiation	39
Cosmic radiation	31
Terrestrial radiation	28
Manmade:	
X-rays and nuclear medicine	50
Consumer products (including drinking water)	11
Miscellaneous	1
Total	**360**

Source: *U.S. Environmental Protection Agency*, Radiation: Risks and Realities, *August 1993.*

The table (left) shows how much each source of ionizing radiation contributes to our average annual exposure. The exposure from radon and its decay products is listed under natural sources. The category "other" under natural sources gives the sum of the exposures from cosmic radiation, terrestrial radiation, and internal radiation (radiation inside the body).

The estimated exposure from radon and its decay products reflects increased concern about exposure to radon. One reason for this concern is that today's emphasis on energy efficiency has resulted in better insulated but less well ventilated buildings. This has increased the likelihood of higher indoor radon concentrations.

In the previous table, the exposure from consumer



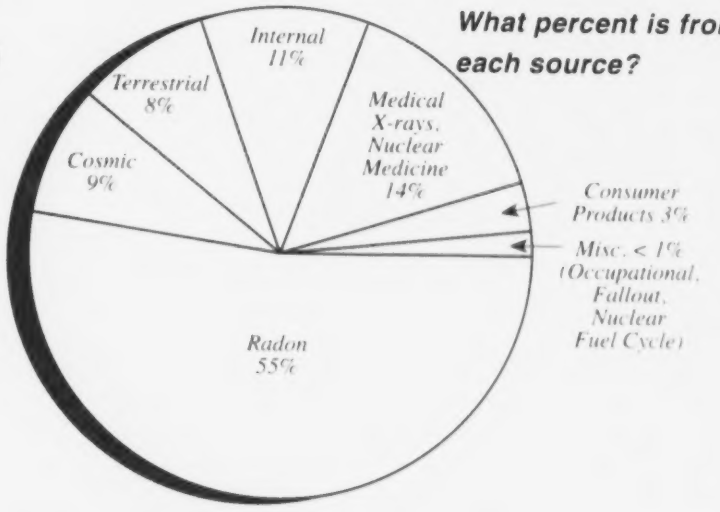
Pathways of Radon

There are new concerns about the possible health effects from radon in indoor air. The concerns arise from new and higher estimates of exposures from radon and its decay products and the higher indoor concentrations resulting from energy-efficient, less-ventilated homes, schools, and other buildings.

products does not include that received from smoking. Although scientists agree that there is radiation exposure from smoking,* current information does not permit a meaningful statistical estimate.

The pie chart at the right shows the percent each source of ionizing radiation contributes to the average individual's exposure of 360 millirem per year.

What percent is from each source?



Source: U.S. Environmental Protection Agency, Radiation: Risks and Realities, *August 1993*.

*Source: *National Research Council: Committee on the Biological Effects of Ionizing Radiation (BEIR V)* The Effects on Populations of Exposure to Low Levels of Ionizing Radiation, *1990, p. 19*.

2.5 Cosmic Radiation

Cosmic radiation originates outside the Earth's atmosphere and is composed of highly penetrating radiation of all sorts, both particles and rays. At sea level, the average annual exposure from cosmic radiation is 26 millirem. The following table shows the effect of elevation on cosmic radiation exposures.

What is the average exposure from cosmic radiation?
How does elevation affect exposure to cosmic radiation? Why?

Effect of Elevation, in Feet, on Cosmic Radiation Exposures (MREM/YR)

(Exposures reflect 10% reduction for shielding from buildings/structures)

0 (sea level) 26	4,000 39
500 27	6,000 52
1,000 28	8,000 74
2,000 31	10,000 107

Source: National Research Council: Committee on the Biological Effects of Ionizing Radiation (BEIR III) The Effects on Populations of Exposure to Low Levels of Ionizing Radiation, 1980. *(The latest version of this report, BEIR V, does not provide additional information on the effect of elevation on exposure.)*

Jet Flight Exposure

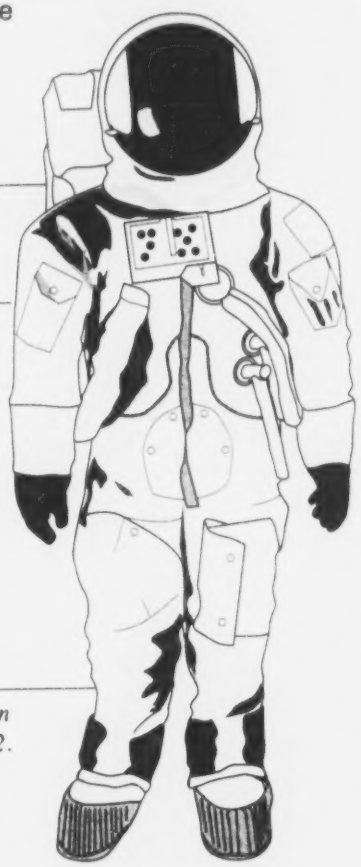
Do we get increased exposure from jet flights?

Because the atmosphere gets less dense as elevation increases, the cosmic radiation exposure rises with increasing elevation. Therefore, passengers on a jet airplane receive an additional radiation exposure from cosmic rays during the flight. According to the National Council on Radiation Protection and Measurements, cosmic exposure at 11,887 meters (39,000 feet) is 0.5 millirem per hour.

Apollo Flight Exposures

Did the astronauts receive increased exposure?

It may not have occurred to you that our astronauts in Earth orbit or on Moon missions received increased radiation exposure from cosmic rays. The table shows the estimated exposures received by our astronauts on the various Apollo missions.



Estimated Exposures Received By Astronauts On the Apollo Missions

Apollo Mission Number	Launch date	Type of orbit	Duration Mission (hours)	Exposure (mrem)
VII	Aug. 1968	Earth orbital	260	120
VIII	Dec. 1968	Circumlunar	147	185
IX	Feb. 1969	Earth orbital	241	210
X	May 1969	Circumlunar	192	470
XI	July 1969	Lunar landing	182	200
XII	Nov. 1969	Lunar landing	236	~200
XIV	Jan. 1971	Lunar landing	286	~500
XV	July 1971	Lunar landing	286	~200

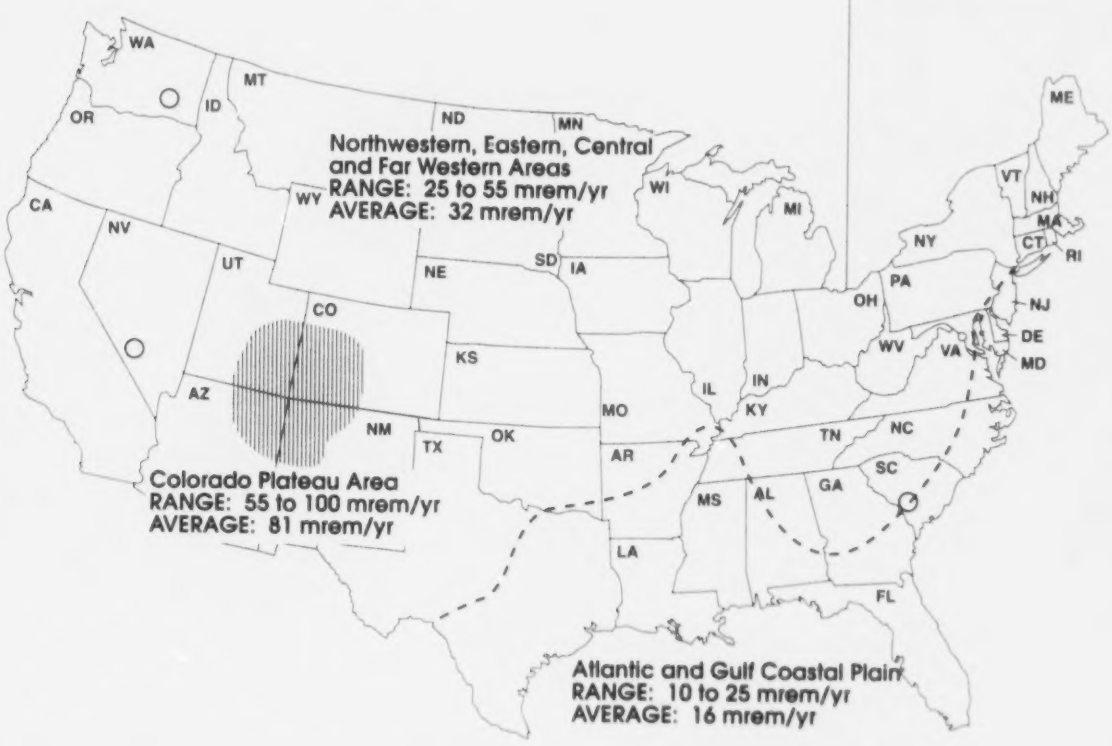
Source: United Nations Scientific Committee on the Effect of Atomic Radiation (UNSCEAR), Ionizing Radiation: Sources and Biological Effects, *1982.*

2.6 Terrestrial Radiation

The average exposure to an individual in the United States from terrestrial radiation is about 28 millirem per year. However, terrestrial exposures do show some variations over the country, and the average annual exposure of 28 millirem takes population densities in the regions into account. On the coastal plains of the Atlantic and Gulf regions, the average exposure is 16 millirem per year. This average takes population density in the regions into account. In a region on the eastern slopes of the Rocky Mountains where Denver is located, the average terrestrial radiation exposure is 63 millirem per year. For the rest of the country, it is about 32 millirem per year, with little variation. The main contributors to terrestrial radiation are a radioactive isotope (radioisotope) of potassium and radioisotopes of the uranium and thorium series.

What is the average U.S. exposure from terrestrial radiation?

What elements contribute to terrestrial radiation?



Source: *Adapted from National Research Council: Committee on the Biological Effects of Ionizing Radiation (BEIR III).* The Effects on the Populations of Exposure to Low Levels of Ionizing Radiation, *Washington, Protection and Measurements*, NCRP Report No. 93, September 1987, p. 10. *Also from U.S. Environmental Protection Agency,* Radiation: Risks and Realities, *August 1993.*

SR-9

2.7 Radioactivity in Food

How much exposure does our food contribute?

Potassium and carbon in the food we eat contribute about 19 millirem to the average annual internal exposure of 39-40 millirem. The main contributor to the exposure (about 18 millirem) is from potassium-40, a radioactive isotope of naturally occurring potassium. Slightly more than 1 millirem is contributed by radioactive carbon-14 in our food.

Like uranium and thorium, potassium-40 was present when the Earth was formed. Unlike potassium-40, radioactive carbon-14 is formed by the action of cosmic radiation on our atmosphere.

How does potassium become part of our food?

Each gram of natural potassium has a very small amount of radioactive potassium-40. Average soil contains about 1.5 percent natural potassium and is the source of potassium in our food. Carbon-14 in the atmosphere becomes incorporated in the natural carbon of growing things that are the source of carbon in our food.

How much potassium and carbon are in our bodies?

The body maintains a natural potassium content of about 0.2 percent by weight and a carbon level of about 23 percent. Small amounts of the potassium and carbon in the food we eat are used to maintain these levels, and the rest is eliminated.

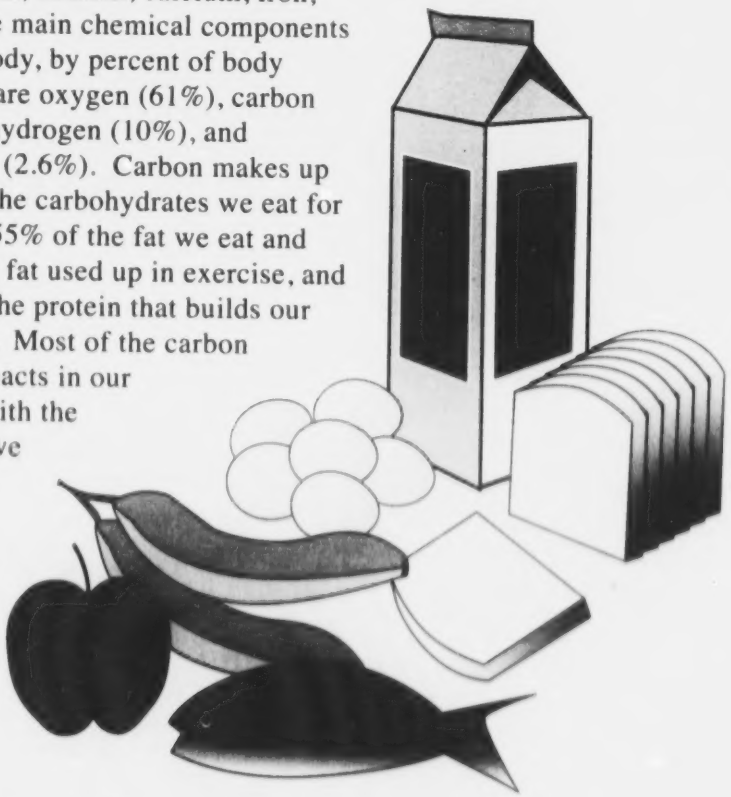
Potassium and Carbon in Our Bodies

Potassium is important for healthy body function. It helps maintain fluid pressure and balance within cells. It is also important in normal muscle and nerve response and in maintaining heart rhythm. Even a temporary potassium deficiency can result in serious upsets of body functions.

Why is potassium important to health?

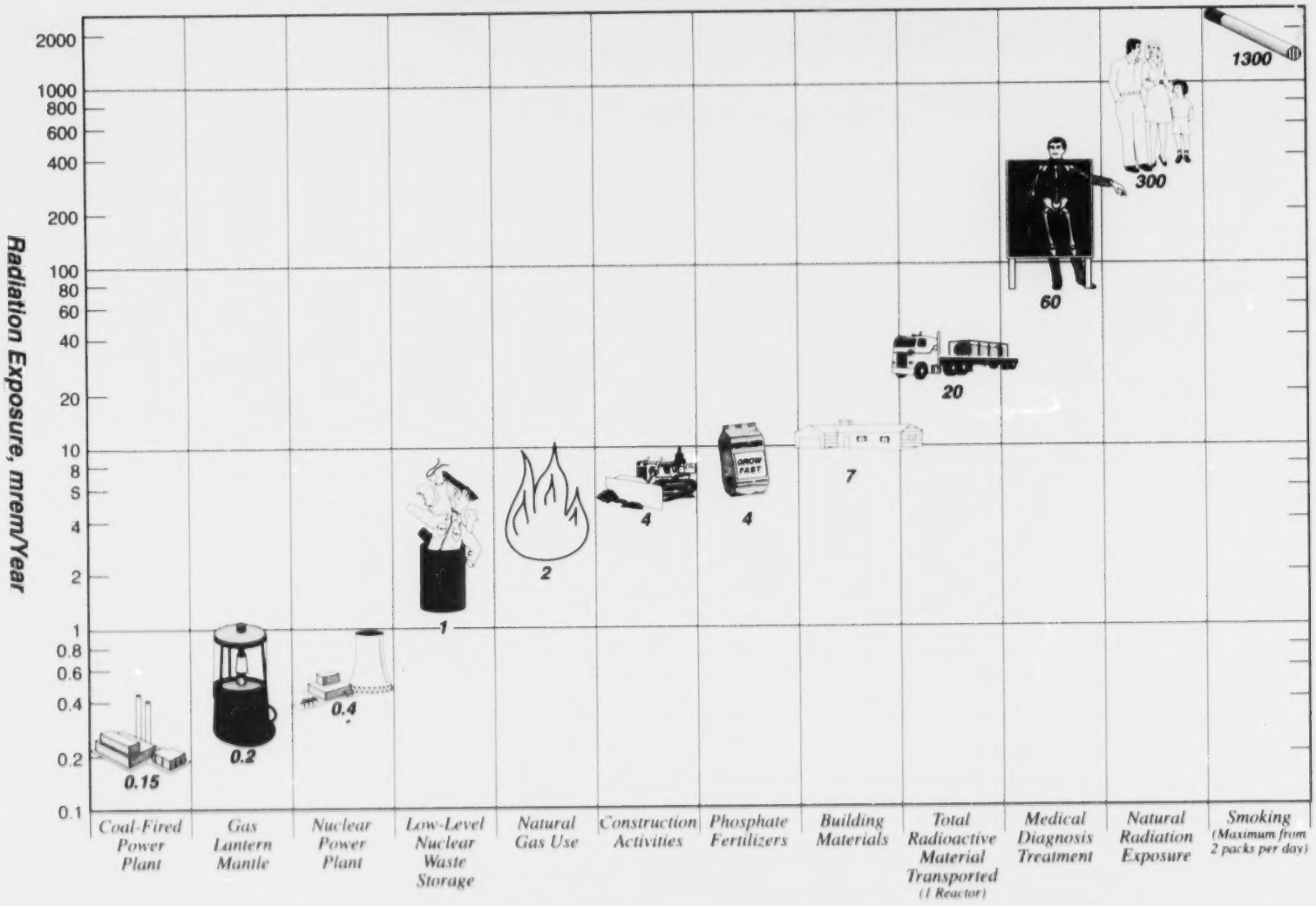
Carbon is also important. Not counting the small amounts of minerals in the body (such as potassium, sodium, calcium, iron, etc.), the main chemical components of the body, by percent of body weight, are oxygen (61%), carbon (23%), hydrogen (10%), and nitrogen (2.6%). Carbon makes up 45% of the carbohydrates we eat for energy, 55% of the fat we eat and the body fat used up in exercise, and 50% of the protein that builds our muscles. Most of the carbon we eat reacts in our bodies with the oxygen we breathe and is exhaled as carbon dioxide (CO_2).

Why is carbon important?



This provides the heat and energy we need to perform our daily work. That's what we mean when we say we "burn" calories during exercise.

Some Exposures from Manmade Sources Compared to the Average Natural Radiation Exposure



This chart compares the highest possible dose received from a number of activities to the average annual individual exposure to all sources of radiation. This chart was compiled in 1991 and reflects the most current numbers available at that time.

2.8 Manmade Sources

What are some exposures to manmade sources?

The figure at the left gives the annual exposures from some important manmade sources of ionizing radiation. The number given is the exposure in millirem per year to the individual receiving the highest exposure. For comparison purposes, the figure includes the average annual exposure to an individual in the United States from natural radiation sources.

The 0.1 millirem per year exposure from the transportation of all radioactive materials includes shipments to and from nuclear facilities. Shipments of waste are included.

The exposure of 1300 millirem per year from smoking deserves a special explanation. This is the maximum exposure from smoking two packs of cigarettes a day, estimated by the National Council for Radiation Protection and Measurements. It is not a statistical average individual exposure.

About the Graph

You are used to looking at graphs that use a linear scale, in which all divisions on an axis are equal. This graph uses a logarithmic scale for the y axis. The main divisions are:

100	-	1,000
10	-	100
1	-	10
0.1	-	1

The spacing represents powers of 10: 10^0, 10^1, 10^2, 10^3. The logarithmic scale allows us to represent a wide range of information in a much smaller space than would be possible with a linear scale.

The spacings within the main divisions are not equal. (They are not linear.) In a linear scale, 5 is half the distance between 1 and 10. In a log scale, 5 is 7/10 of the distance between 1 and 10; 50 is 7/10 of the distance between 10 and 100. And so forth.

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2.9 Ionizing Radiation and High-Level Waste

Curie –
About 37 billion disintegrations (or counts) per second. *The number of curies is a measure of activity used to classify nuclear waste.*

A spent fuel assembly from the reactor of a nuclear powerplant will contain hundreds of thousands of *curies* of radioisotopes. When these radioisotopes undergo radioactive decay, they release both alpha and beta particles and gamma rays. While the metal in the fuel rods making up the fuel assembly will stop alpha and beta particles, it will not stop gamma rays. Therefore, we store fuel assemblies in deep pools of water at the powerplant sites to protect workers from the ionizing gamma rays coming from the fuel assemblies. Workers also use shielding when handling a spent fuel assembly outside the pool.

At a powerplant, what protects workers and the environment from exposure to radiation from spent fuel?

Shielding is the primary method of protecting workers and other people from a source of radiation. However, it is also true that the further one is from a source of radiation, the less radiation one receives. Reducing the time of exposure to a radiation source also will result in a lower exposure. Radiation workers not only use shielding to protect themselves, but they also wear radiation monitors to measure the amount of radiation they receive during their work periods.

How do shielding, distance, and time protect workers from radiation?

After 10 years of storage, the nuclear fuel will have lost 90 to 95 percent of its radioactivity. Workers would still use shielding and remote operation to handle a spent fuel assembly. To protect people and the environment, workers enclose spent fuel assemblies in a heavy shielded cask for transportation to a disposal facility. At the disposal facility, the spent fuel assemblies will be placed in disposal containers and then in the geologic repository deep underground. Radiation monitors outside the repository, above the spent fuel, will not be able to detect any of the direct gamma radiation from the fuel because of the large amount of rock shielding the fuel.

How are people and the environment protected from ionizing radiation during disposal?

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Ionizing Radiation Exposure in the United States

Source	Estimated average annual exposure in the U.S. population (millirem)
Natural sources	
Radon	200
Internal radiation	39
Cosmic radiation	31
Terrestrial radiation	28
Manmade:	
X-rays and nuclear medicine	50
Consumer products (including drinking water)	11
Miscellaneous	1
Total	**360**

Source: U.S. Environmental Protection Agency, Radiation: Risks and Realities, *August 1993.*

The percentage contribution to the annual average exposure from various radiation sources is illustrated in the pie chart.

1. Looking at the pie chart, what percentage of the annual average exposure comes from natural sources of radiation (radon, cosmic, terrestrial, internal)?

   (83%)

2. What is the percentage for manmade sources?

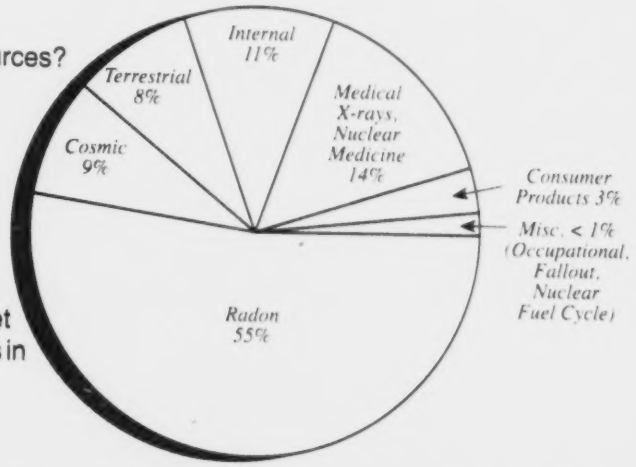
   (17%)

3. What is our annual internal exposure, in millirem?

   (40 mrem or 39.6 millirem)

4. What is the average exposure we get annually from radon and its decay products in the air we breathe in millirem?

   (198 mrem or 200 mrem)



PENNIUM-123

Purpose:

Radioactive materials become less radioactive over time as a result of a process known as radioactive decay. An understanding of radioactive decay is essential to an understanding of the plans for permanent disposal of radioactive waste.

This activity is one in a series designed to convey factual information relevant to radioactivity, radioactive materials, and radiation in a manner students will find appealing and fun, as well as educational.

Concepts:

1. Radioactive materials become less radioactive over time through the process of radioactive decay.
2. Radioactive decay curves may be illustrated by graphing the flipping of a coin.

Duration of Lesson:

One 50-minute class period

Objectives:

As a result of participation in this activity, the learner will be able to:

1. collect data;
2. arrange the data on a chart; and
3. graph the collected and charted data.

Skills:

Collecting and organizing data, deductive reasoning, drawing conclusions, filling in a chart, plotting data on a graph, reading a graph

Vocabulary:

Half-life, isotope, radioactive decay

Materials:

Activity Sheet

Pennium-123, p. 105

Other

1 penny for each participant

1 box (if alternate experiment is conducted)

Suggested Procedure:

1. Complete as described on handout.
2. This activity may be adapted for a shorter demonstration, or for students to do on an individual basis as follows:

Put pennies in a box, shake them, and count "heads" and "tails." Remove "heads." Record the numbers that were "heads" on the chart. Repeat until the box is empty. Complete the chart and graph as described on handout.

Note: To be sure of getting accurate results, ask who got "heads" and who got "tails" before announcing who is "out." This is sometimes necessary because students like to continue playing.

Sample Discussion Questions:

1. What shape line did you get?
   (A steep curve with a flat bottom.)
2. Why does this curve have this shape?
   (There are a large number of people that begin the activity, and as each half-life passes there are fewer and fewer to take half from. The total number of participants is decreasing at a decreasing rate.)
3. After five turns how many students are out?
   (Answers will vary depending on the number of participants.)
4. Why isn't the above number half of the total?
   (It was one-half after the first turn.)
5. Will the number of students out always be one-half the number of students who flipped?
   (No, this is an average, just as radioactive decay is random, so is flipping a coin.)
6. Can we predict which students will be out each flip?
   (No.)
7. Compare this activity to radioactive decay.
   (Radioactive decay is a random process. We cannot predict which atom will decay or when a particular atom will decay. We also cannot expect exactly half of the total number of isotopes to decay during every half-life.)

Teacher Evaluation of Learner Performance:

Collect and grade student activity sheets to verify comprehension.

Enrichment:

Radioactive Decay Series, pp. SR-31, 139
Chart of Some Important Transitions in Spent Fuel, p. 149
Hazards of Some Isotopes in Spent Fuel Compared to the Hazard of Uranium Ore, p. 153

PENNIUM-123

The participants will simulate radioactive decay and plot the decay of an isotope of the imaginary element pennium.

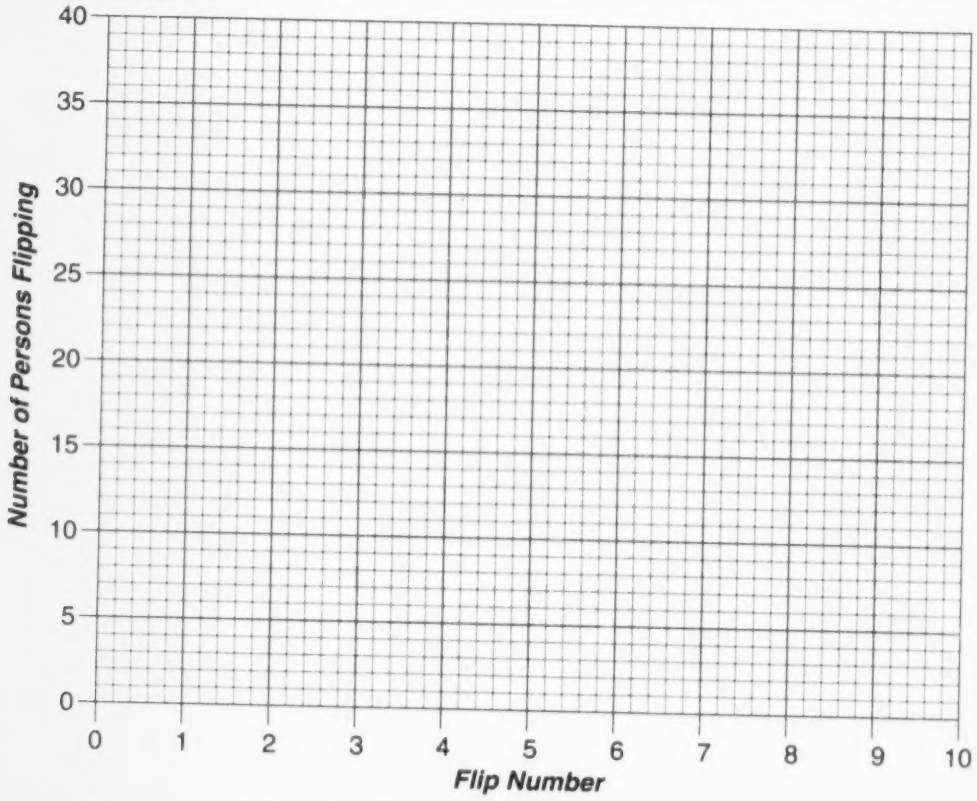
In this activity, everybody has a penny. The discussion leader and participants flip the pennies.

Everyone whose penny matches the leader's flip has "decayed," while those whose penny is different are still "radioactive."

Each time, those who have "decayed" are out.

Count the number out and record the results as indicated on the chart. Then those who are still playing flip again. Continue until everyone is out. Plot the results on the graph below.

Flip Number	Number Decayed	Number Radioactive
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		



Is the number of participants out each turn always one half the number flipped? *No.*

Why or why not? *(This is an average. Just as radioactive decay is random, so is flipping a coin.)*

HALF-LIVES

Purpose:

This lesson will point out that radioactive materials become less radioactive over time through the process of radioactive decay. Additionally, students will learn that the time for radioactive materials to lose essentially all their radioactivity can vary from seconds to thousands of years and that the half-life of a radioisotope is the time it takes for a quantity of that radioisotope to lose half of its radioactivity. The necessity for providing safe disposal for materials with high specific activities as well as those containing radioisotopes with very long half-lives will be discussed.

Concepts:

1. Radioactive materials become less radioactive over time through the process of radioactive decay.
2. The time for radioactive materials to lose essentially all their radioactivity can vary from seconds to thousands of years.
3. Radioactive materials with the highest activities per unit weight decay the fastest.
4. Each radioactive isotope has its own distinct half-life.

Duration of Lesson:

One 50-minute class period

Objectives:

As a result of participation in the lesson *Half-lives*, the learner will be able to:

1. complete a chart on half-lives of significant radioisotopes;
2. differentiate which three radioisotopes have the highest and lowest specific activity; and
3. explain the significance of the information on the half-life chart as it relates to permanently disposing of radioactive waste.

Skills:

Analyzing, calculating, critical thinking, drawing conclusions, evaluating, filling in a chart, interpreting

Vocabulary:

Fission, spent fuel, transuranic

Materials:

Activity Sheets

Half-lives, p. 107

Background Notes

Half-life Measurements, p. 27

Suggested Procedure:

1. If you have not already done so in Unit 1, read and discuss the reading entitled *Nuclear Waste: What Is It? Where Is It?* A question/answer type study guide has been supplied to facilitate class discussion.
2. Have students fill in the chart and answer the questions on the activity entitled *Half-lives.* Discuss the activity as a group.

Sample Discussion Questions:

1. Is it possible to predict when a radioactive isotope will decay and produce radiation?

   (Radioactive isotopes decay at random, and it is impossible to predict which one will decay next. However, when these atoms are gathered together it is possible to see a pattern. This pattern is described by use of the term half-life.)

2. What is half-life?

   (The amount of time it takes for a quantity of a given isotope to lose half of its radioactivity is known as half-life.)

3. Discuss the meaning of the term "decay chain."

   (This is the ordered process that certain elements pass through in order to become stable. For instance, the isotope uranium-238 transforms into many different isotopes before it becomes stable lead. Some isotopes may change in the next second, some in the next hour, some tomorrow, and some next year; others will not decay for thousands of years. Half-lives range from fractions of a second to several billion years.)

Teacher Evaluation of Learner Performance:

Student response during discussion and on activity sheets will indicate level of comprehension.

Enrichment:

Using Half-Lives, p. 133

HALF-LIFE MEASUREMENTS

Two characteristics of chemical elements and, in the present instance, of radioisotopes make the precise measurement of radioactive half-lives possible. One is the enormous number of atoms in even the smallest amount of a radioisotope. The other is that, as long as we are able to accurately measure the quantity or amount of a radioisotope, we know precisely how many atoms of that isotope we have.

The latter was the ultimate result of an 1811 hypothesis of an Italian physicist, Avogadro, who postulated that equal volumes of all gases at the same temperature and pressure contained the same number of molecules. It has since been developed that a gram molecular weight of a chemical element—the weight in grams equal to the atomic weight—contains 6.022×10^{23} atoms of that element. The number is known as Avogadro's number and when written out looks like this:

602,200,000,000,000,000,000,000.

We have already learned that the atomic weight of an isotope is equal to the sum of the protons and neutrons in its nucleus. Hence, when we know the weight in grams of a quantity of a radioisotope, we know the number of atoms of the isotope and with the proper equipment can measure the number of atoms decaying per unit time.

For example, the number of atoms in one gram of potassium-40 is equal to:

$$\frac{(6.022 \times 10^{23})}{40} = 1.506 \times 10^{22} \text{ atoms}$$

The number of atoms in one gram of uranium-238 is:

$$\frac{(6.022 \times 10^{23})}{238} = 2.53 \times 10^{21}$$

All this results in the fact that relatively small amounts of radioisotopes with extremely long half-lives have significant activity. For instance, one gram of thorium-232 with a half-life of 14 billion years has more than 4100 disintegrations per second.

The precise measurement of half-lives requires more sophisticated instruments than the relatively simple instruments that simply detect the presence of radiation, such as a Geiger counter. More sophisticated instruments and techniques can measure precisely the absolute number of alpha, beta, and gamma emissions from a measured amount of a radioactive material.

Half-life measurements: **The following are methods for determining half-lives under the given conditions.**

1. Radioisotopes with half-lives of several seconds to years:

   Plot the activity of a quantity of the radioisotope as a function of time and determine the time when half has decayed or will decay.

2. Radioisotopes with half-lives below a few seconds:

   a. For gases or solutions containing a known concentration of a radioisotope, flow them past a counter at a known rate. Plot activity versus time.

   b. Attach a solid containing a known quantity of a radioisotope to a rapidly revolving wheel turning at a known rate past a counter. Plot X (counts) versus time.

3. Half-lives less than a second must be measured electronically.

4. Radioisotopes with extremely long half-lives where the rate of decay is essentially constant with time:

   Determine the decay constant. The decay constant is a unique characteristic of each radioisotope and is the fraction of the activity of a quantity of the radioisotope that decays per unit time. It is identified by the lower case of the Greek letter Lambda, λ.

   Know the number of atoms of the radioisotope.

   Count the number of atoms decaying per unit time.

   Then (decay constant) x (number of atoms) = counts/unit time

   and decay constant = $\frac{\text{(counts/unit time)}}{\text{(number of atoms)}}$

   but we know: decay constant = $\frac{0.693}{\text{half-life}}$

   Hence, the half-life in:

   seconds = $\frac{0.693\ \text{(number of atoms)}}{\text{(counts/second)}}$

   hours = $\frac{0.693\ \text{(number of atoms)}}{\text{(counts/hour)}}$

   days = $\frac{0.693\ \text{(number of atoms)}}{\text{(counts/day)}}$

   years = $\frac{0.693\ \text{(number of atoms)}}{\text{(counts/year)}}$

HALF-LIVES

The half-lives of some significant radioisotopes are listed below. The radioisotopes listed are fission products, naturally occurring radioisotopes, and transuranics. All are present in spent fuel. Fill in the chart below. (The first problem has been done as an example. y=year; d=day; h=hour.)

Radioisotopes	Type of Decay	Half-Life	How long will it take to lose 1/2 of its radioactivity?	How long will it take to lose 3/4 of its radioactivity?	How long will it take to lose 7/8 of its radioactivity?	Specific Activity (curies/gram)
Fission Products						
Gases						
krypton - 85	Beta	10.72 y	10.72 y	21.44 y	32.16 y	392
xenon - 133	Beta	5.27 d	*5.27 d*	*10.54 d*	*15.81 d*	186,000
Solids						
strontium - 90	Beta	28.1 y	*21.1 y*	*56.2 y*	*84.3 y*	141
molybdenum - 99	Beta	66.7 h	*66.7 h*	*133.4 h*	*200.1 h*	474,000
iodine - 131	Beta	8.07 d	*8.07 d*	*16.14 d*	*24.21 d*	123,500
cesium - 137	Beta	30.2 y	*30.2 y*	*60.4 y*	*90.6 y*	86.4
cerium - 144	Beta	285 d	*285 d*	*570 d*	*855 d*	3,182
Natural Elements						
uranium - 235	Alpha	710,000,000 y	*7.1×10^8 y*	*1.42×10^9 y*	*2.13×10^9 y*	0.00000241
uranium - 238	Alpha	4,500,000,000 y	*4.5×10^9 y*	*9.0×10^9 y*	*1.35×10^{10} y*	0.000000334
Transuranics						
plutonium - 238	Alpha	86 y	*86 y*	*172 y*	*258 y*	17.47
plutonium - 239	Alpha	24,400 y	*24,400 y*	*48,800 y*	*73,200 y*	0.0613
plutonium - 240	Alpha	6,580 y	*6,580 y*	*13,160 y*	*19,740 y*	0.226
plutonium - 241	Beta	13.2 y	*13.2 y*	*26.4 y*	*39.6 y*	112
americium - 241	Alpha	458 y	*458 y*	*916 y*	*1,374 y*	3.24
americium - 243	Alpha	7,370 y	*7,370 y*	*14,740 y*	*22,110 y*	0.200

The higher the specific activity of the radioisotope, the more intense the radioactivity and the more particles or rays emitted in a given time period.

1. Which three radioisotopes have the highest specific activity (curies per gram)?
   (molybdenum - 99) *(xenon - 133)* *(iodine - 131)*
2. Which three radioisotopes have the lowest specific activity?
   (uranium - 238) *(uranium - 235)* *(plutonium - 239)*
3. What is generally the relationship between specific activity and half-life? Circle the correct word: The more intense the radioactivity, the (longer? (shorter?)) the half-life.

In your own words, explain the significance of all of the above information as it relates to permanently disposing of radioactive waste.

(Isotopes with the greatest specific activity decay fastest. Half-lives of isotopes in spent fuel range from hours to thousands of years. Safe disposal requires that we provide for materials that have high specific activities as well as those with very long half-lives.)

SUMMARY

2.10 Ionizing Radiation

Radiation is energy that moves through space in the form of waves and particles. We are constantly exposed to radiation of all kinds, but the radiation of most concern is ionizing radiation. Ionizing refers to the ability of higher energy radiation to create electrically charged particles called ions in the material it penetrates, including human tissue.

What is radiation?

What is ionizing radiation?

Radioactive materials emit ionizing radiation in the form of alpha and beta particles and X-rays and gamma rays. An alpha particle is essentially a helium nucleus with a positive charge of 2 (2 protons) and an atomic weight of 4 (2 protons and 2 neutrons). Beta particles are negative electrons. X-rays and gamma rays are waves of pure energy.

What form of ionizing radiation is emitted by radioactive materials?

2.11 Identification of Atoms

Because the ionizing radiation from radioactive materials comes from the nuclei of the radioactive atoms in the material, it is called "nuclear radiation." The individual radioactive atoms, which are identified by the number of protons and neutrons in their nuclei, are often called radioisotopes. The number of protons (i.e., the atomic number) determines what an atom is. For example, uranium has the highest naturally occurring atomic number, 92.

What is nuclear radiation?

What makes an atom what it is?

2.12 Sources of Radioisotopes

There are many naturally occurring radioisotopes in the world. With a few important exceptions, nearly all result from the uranium and thorium present when the Earth was formed. There are also many manmade radioisotopes, most created by the use of uranium in nuclear reactors.

Where do radioisotopes come from?

2.13 Radioactive Decay and Half-Life

Radioactive materials become less active with time by radioactive decay. The decay of a radioisotope is measured in half-lives. The half-life of a radioisotope is the time it takes for a quantity of that radioisotope to lose half of its activity. Half-lives of radioisotopes range from a fraction of a second to more than a billion years. For example, radioisotopes in spent nuclear fuel will be hazardous for hundreds of thousands of years.

2.14 Sources of Exposure

What is the annual average individual radiation exposure? How much from natural sources? How much from other sources?

The annual average radiation exposure of an individual in the United States, from all sources, is estimated at 360 mrem. Of this, 82% comes from natural sources: outer space, the air we breathe, the earth around us, and the food we eat. Essentially, the rest results from medical X-rays, nuclear medicine, and consumer products. Nuclear power and miscellaneous sources contribute much less than 1 percent.

2.15 Radiation Protection

It is important to use caution in handling highly radioactive materials. The shielded casks used to store or transport spent nuclear fuel are examples of how we use shielding to protect workers, the public, and the environment from exposure to ionizing radiation.

Planning for the permanent disposal of our Nation's nuclear waste is a complex undertaking that presents numerous challenges in terms of radiation protection. The waste must be transported safely to the disposal site. At the disposal site, the waste must be handled safely and packaged properly. Finally, it must be permanently isolated from the public and the environment for long periods of time.

ATOMS AND ISOTOPES

Purpose:

The purpose of this introductory lesson is to acquaint students with concepts about atoms and isotopes and to begin exploration of radioactivity and its relation to radiation, the chemical elements, and the nature of atoms.

Concepts:

1. There are 92 naturally occurring chemical elements, some of which are radioactive.
2. An atom is the smallest part of a chemical element that has all the chemical properties of the element.
3. Each atom has a nucleus that determines its chemical properties.
4. The nucleus of a radioactive atom spontaneously emits a particle, which changes the atom into a different chemical element.

Duration of Lesson:

One 50-minute class period

Objectives:

As a result of participation in this lesson, the learner will be able to:

1. define atom, atomic number, atomic weight, and isotopes;
2. name the parts of an atom;
3. discuss everyday applications and uses of radioactive materials; and
4. use the Periodic Table.

Skills:

Analyzing, discussing, drawing (optional), expressing opinions, interpreting/using charts (optional), reading comprehension

Vocabulary:

Atom, atomic number, atomic weight, electron, isotope, molecule, neutron, nucleus, proton, radiation, radioactive decay

Materials:

Reading Lesson

Atoms and Isotopes Review, p. SR-17

Activity Sheets

Atoms and Isotopes Review, p. 109
The Chemical Elements and Isotopes, p. 111
Periodic Table, p. 115
Chemical Element Worktable, p. 117

Suggested Procedure:

1. Assign the reading lesson entitled *Atoms and Isotopes Review.*

   It may be helpful to begin by explaining to students that the reading lesson and activities in which they will participate cover concepts about atoms and isotopes. Discuss why the number of naturally occurring elements is smaller than the number of elements on the periodic table.

   (We know for certain that 92 elements exist in nature. Physical evidence indicates that at least two others are present from time to time because they are part of the decay chain of some naturally occurring elements. Students may become confused because the periodic table indicates 103 elements. The reason for the discrepancy is that scientists have produced small amounts of very heavy elements in the laboratory.)

2. Engage students in a class discussion upon completion of the reading lesson.

Sample Discussion Questions:

1. If atoms are so small that we can't see them, how do we know they really exist?

   (Scientists learn about atoms through indirect observation. They study the properties of atoms that can be measured in some way. We study other phenomena the same way. For example, we can't see the wind, but we can see it blow leaves about, and therefore we know it exists. We know its properties and its effects.)

2. If an atom is considered the smallest unit of matter, how can we say that atoms are made of smaller particles such as protons, electrons, and neutrons?

   (The atom is the smallest part of matter which retains all of the chemical characteristics of an element. Electrons, protons, and neutrons are fundamental particles which make up the atoms of all elements.)

3. Why are protons used to identify elements?

   (The number of protons in an atom is used to identify an element because all isotopes of an element have the same number of protons.)

4. What is the difference between an atom and a molecule?

   (A molecule can be a combination of several atoms of the same element or of different elements. For example, a molecule of hydrogen gas is made of 2 hydrogen atoms combined with 1 oxygen atom, H_2O. A molecule is always made of atoms; atoms are not made of molecules.)

5. How do isotopes differ from one another?

   (Isotopes of a specific element differ from one another in the number of neutrons in their nuclei. They have the same number of protons in their nuclei and therefore, they have the same chemical properties but not the same atomic weight. They are all atoms.)

6. Why is the atomic weight sometimes a fraction?

   (The atomic weight is the average of the weights of the isotopes of an atom.)

3. Assign the reading review *Atoms and Isotopes* and the activities entitled *Chemical Element Worktable* to be completed in class.

   You may wish to review rounding off numbers with the class and do the first example as a group to assure understanding.

   Additionally, it may be helpful to discuss the steps involved in filling in the names of isotopes. Be sure that students know they must use the list of elements and their symbol to find the isotope symbol. They must also know that they use the symbol to find the correct box for the element on the periodic table, and that they add the number of protons and neutrons to identify the isotopes.

4. Assign the following for homework:

   (a) Have students write a 1 or 2 sentence description of the difference between radiation and radioactivity.

   (Students should be aware that radiation is energy that moves through space in the form of waves particles. Radioactivity is the property of some chemical elements that spontaneously emit radiation.)

   (b) Ask students to list as many everyday uses of radiation as they can. They may look these up, or ask friends and family members to help them, etc.

   (Answers will vary. However, you should be looking for such responses as:

   Radioactive materials have many different uses. They are used in medicine, scientific research, industry, and to help generate electricity.

   Doctors have learned many different ways to use radioactive materials in the treatment and diagnosis of various diseases, including cancer.

   We also use radiation to label things. When substances are labeled with radioactive elements, we can trace the path these substances take through living plants or animals.

   Industry uses radiography to check the quality of many different products. In addition, radioactive elements are used in thickness gauges, for analyzing evidence from the scene of a crime, for preserving foods, for dating art and antiques, and for generating electricity.)

Teacher Evaluation of Learner Performance:

Student completion of activities and participation in discussion will indicate level of comprehension.

ATOMS AND ISOTOPES REVIEW

Nuclear waste requires special handling and disposal because it is radioactive and emits radiation. In order to understand radioactivity and radiation, we must first learn about atoms, how atoms react with each other to form "molecules," and about special forms of atoms called isotopes.

2.16 Introduction

What are things made of?

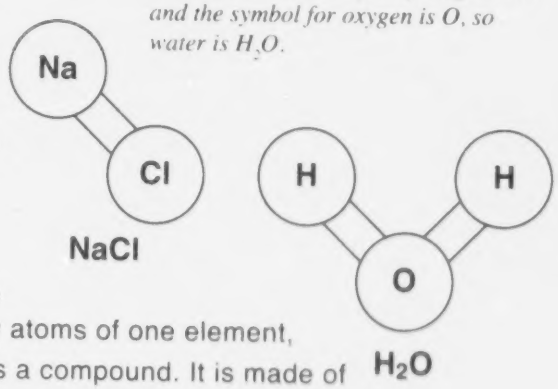
What do you suppose would happen if you took a lump of salt and began to break it up into smaller and smaller pieces? Sooner or later you would get pieces so small that you wouldn't be able to see them. The smallest piece that still is salt is called a *molecule*.

Everything is made of molecules—tables, chairs, sugar, salt, and even the cells of your own body. However, all molecules are **not alike**. A molecule of sugar is different from a molecule of salt.

What is an atom?

But that is not the whole story. Molecules are made of even smaller parts, which are called atoms. Atoms are so small that it takes millions of them to make a speck of dust. We know that at least 92 different kinds of atoms occur in nature. These different kinds of atoms are known as elements. Combining atoms of different elements or atoms of the same element makes molecules. The kind of molecule depends on which atoms combine. This combining of atoms is called a chemical reaction. In chemical reactions, atoms do not change; instead, they combine with other atoms or separate from other atoms.

The symbol for sodium is Na and the symbol for chlorine is Cl, so table salt is Na Cl; the symbol for hydrogen is H and the symbol for oxygen is O, so water is H_2O.



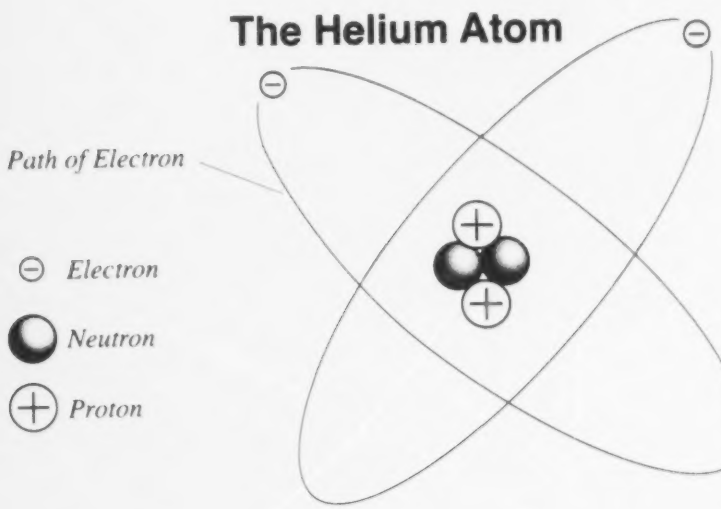
For example, gold is an element, and a bar of pure gold contains only atoms of one element, gold. On the other hand, table salt is a compound. It is made of groups of atoms called molecules. A molecule of table salt has one atom of the element sodium and one atom of the element chlorine. A molecule of water has two atoms of hydrogen and one atom of oxygen. This is why chemists call water H_2O.

So, atoms are basic building blocks of everything in the universe. They are the smallest particles of an element that have all the chemical properties of the element.

2.17 Atoms

What are the parts of an atom?

As small as atoms are, they are made of even smaller particles. There are three basic particles in most atoms—*protons*, *neutrons*, and *electrons*.



Protons carry a positive electrical charge. Neutrons have no electrical charge. Protons and neutrons together make a bundle at the center of an atom. This bundle is the *nucleus*.

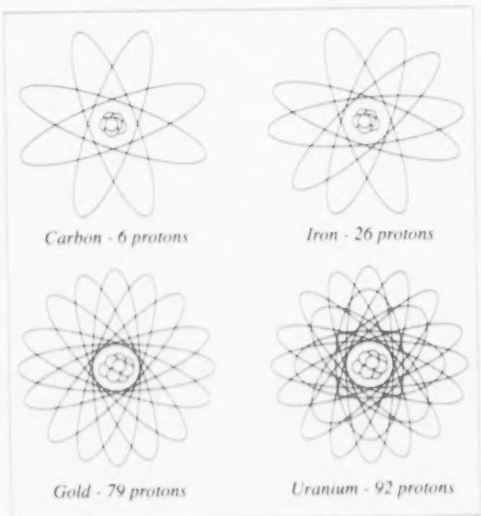
Electrons have a negative electrical charge and move around the nucleus. Normally, an atom has the same number of protons and electrons.

What charges do the parts of the atom carry?

Does the atom have an electrical charge?

If the positively charged protons and the negatively charged electrons are equal in number, they balance each other. As a result, the atom has no electrical charge.

We use protons to identify atoms. For instance, an atom of oxygen has 8 protons in its nucleus. Carbon has 6, iron 26, gold 79, lead 82, uranium 92, and so on.



2.18 Isotopes

The nucleus in every atom of an element always has the same number of protons. However, the number of neutrons may vary. Atoms that contain the same number of protons, but different numbers of neutrons, are called *isotopes* of the element.

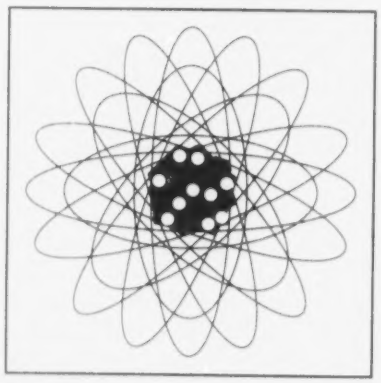
What is an isotope?

All atoms are isotopes. To show which isotope of an element we are talking about, we total the number of protons and neutrons. Then we write the sum after the chemical symbol for the element. For example, in the nucleus of one isotope of uranium there are 92 protons and 143 neutrons. We refer to it as uranium-235 or U-235 (92 + 143 = 235). A second uranium isotope, which contains 3 additional neutrons, is uranium-238 or U-238 (92 + 143 + 3 = 238). (The number may also be written in superscript before the symbol: ^{235}U or ^{238}U.)

How are isotopes identified?

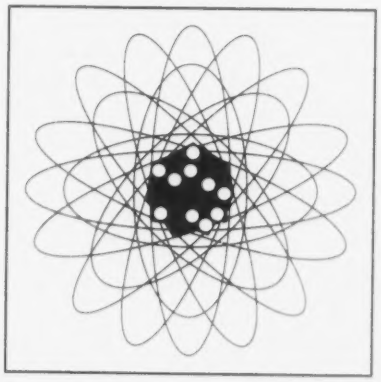
Isotopes of a given element have the same chemical properties, but they may differ in their nuclear properties. Also, isotopes of an element have different numbers of neutrons and the same number of protons. However, some proton-neutron combinations are more stable than others.

Uranium-235



92 + 143 = 235

Uranium-238



92 + 143 + 3 = 238

Some unstable isotopes stabilize themselves by emitting or shooting out energy rays similar to X-rays. Others may emit particles from their nuclei and change into different elements. These rays and particles are called *radiation*, and the process of isotopes emitting them to become more stable is called *radioactive decay*.

2.19 Summary

Everything is made up of small pieces called molecules. Atoms combine to form molecules. Atoms are the smallest units of an element that have all of the chemical properties of the element. Atoms are composed of smaller particles known as protons, neutrons, and electrons.

Protons have a positive electrical charge, neutrons have no electrical charge, and electrons have a negative electrical charge. Protons and neutrons together form the nucleus or "center" of the atom, and electrons move around the nucleus.

The nucleus of each atom of an element contains the same number of protons, but the number of neutrons may vary. Isotopes of an element are identified by adding the number of protons and neutrons together and writing the sum after the chemical symbol for the element. Unstable isotopes can change from one form to another by emitting particles or energy rays in a process called radioactive decay.

ATOMS AND ISOTOPES REVIEW

A. Select the word that best fits the definition given.

1. *atoms* — the smallest unit of a chemical element that has all the chemical properties of that element
2. *nucleus* — the bundle consisting of protons and neutrons, which is found in the center of an atom
3. *isotopes* — atoms of an element containing the same number of protons, but different numbers of neutrons
4. *proton* — a part of an atom with a positive charge
5. *electron* — a part of an atom with a negative charge

B. Indicate whether each statement is true (T) or false (F) by circling the correct letter. If the statement is false, correct it to make it true.

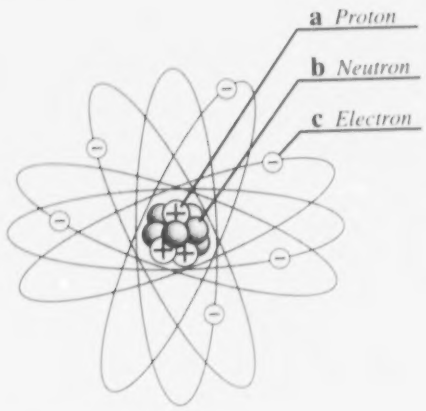
1. Unstable isotopes can change from one form to another by emitting particles and rays. (T) F
2. An atom is identified by the number of protons in its nucleus. (T) F
3. Protons and electrons together make up the nucleus of an atom. *(Protons and neutrons)* T (F)
4. Atoms are so small that humans cannot see them. (T) F
5. Atoms combine to form molecules. (T) F

C. Using the periodic table, tell which elements make the molecules of the following substances.

1. H_2SO_4 — *hydrogen*, *sulfur*, *oxygen*
2. $C_6H_{12}O_6$ — *carbon*, *hydrogen*, *oxygen*
3. KOH — *potassium*, *oxygen*, *hydrogen*
4. $AgNO_3$ — *silver*, *nitrogen*, *oxygen*
5. $ZnCl_2$ — *zinc*, *chlorine*

D. Models

1. Label the model of the carbon atom shown to the right. An atom of carbon has 6 protons, 6 neutrons, and 6 electrons. Remember that protons have a positive (+) charge, electrons have a negative (-) charge, and neutrons have no electrical charge.



2. Draw a model of a helium atom. An atom of helium has 2 protons, 2 electrons, and 2 neutrons. Show protons as ⊕, electrons as ⊖, and neutrons as ○.

CHEMICAL ELEMENT WORKTABLE

DIRECTIONS: Using the list of elements and symbols and the Periodic Table, fill in the chart below. The first example has been completed for you.

Element	Symbol	Atomic Number	Atomic Weight	Atomic Weight (rounded off)	No. of Protons	No. of Neutrons
Gold	Au	79	196.9670	197	79	118
Helium	*He*	*2*	*4.0026*	*4*	*2*	*2*
Carbon	*C*	*6*	*12.0111*	*12*	*6*	*6*
Uranium	*U*	*92*	*238.0400*	*238*	*92*	*146*
Radium	*Ra*	*88*	*226.0000*	*226*	*88*	*138*
Plutonium	*Pu*	*94*	*242.0000*	*242*	*94*	*148*
Oxygen	*O*	*8*	*15.9944*	*16*	*8*	*8*
Radon	*Rn*	*86*	*222.0000*	*222*	*86*	*136*
Nitrogen	*N*	*7*	*14.0067*	*14*	*7*	*7*
Calcium	*Ca*	*20*	*40.0800*	*40*	*20*	*20*

CHEMICAL ELEMENT WORKTABLE

DIRECTIONS: Name the isotopes by filling in all the blanks below.

Isotopes of a given element are atoms with nuclei that have the same number of protons, but different numbers of neutrons. An isotope is identified by the sum of the number of protons and neutrons in its nucleus. To find the symbol, use the list of elements and symbols. To find the correct number of protons, use the periodic table.

The first example has already been completed.

Element	Symbol	Number Protons	Number Neutrons	Name of Isotope
Uranium	U	92	143	Uranium - 235
Uranium	*U*	*92*	146	*Uranium - 238*
Carbon	*C*	*6*	8	*Carbon - 14*
Iodine	*I*	*53*	78	*Iodine - 131*
Strontium	*Sr*	*38*	52	*Strontium - 90*
Cesium	*Cs*	*55*	82	*Cesium - 137*
Thorium	*Th*	*90*	142	*Thorium - 232*

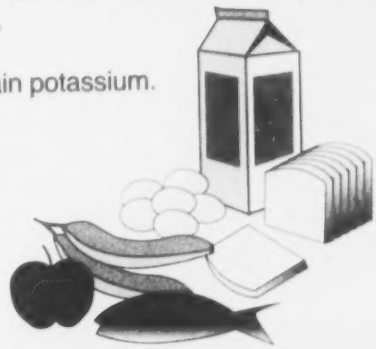
RADIOACTIVITY IN FOOD

Many of the foods that we eat contribute to our internal exposure to radiation. These foods are naturally radioactive. They contain elements like potassium and carbon that are essential for good health and cannot be eliminated from our diets.

Potassium-40

Potassium-40 is a radioactive isotope of naturally occurring potassium. Potassium-40 contributes 18 millirem to our average annual internal radiation exposure.

Directions: Use the chart entitled *Potassium Content and Potassium-40 Activity in Some Selected Foods* to answer the questions that follow.



1. List four foods you have eaten this week that contain potassium.

   (Answers will vary.) _____

   _____

   _____

   _____

2. If the radioactivity of 1 gram of natural potassium is 30 disintegrations per second (d/sec) and a small banana contains about 0.4 grams of natural potassium, what is the number of disintegrations per second of this banana?

$$\frac{1 \text{ gram}}{30 \text{ d/sec}} = \frac{0.4 \text{ grams}}{x \text{ d/sec}}$$

$$\frac{(1 \text{ gram})(x \text{ d/sec})}{1 \text{ gram}} = \frac{(0.4 \text{ grams})(30 \text{ d/sec})}{1 \text{ gram}}$$

$$x = 12 \text{ d/sec}$$

3. The activity of the radioactive potassium-40 in your body is about 60 disintegrations per second per kilogram (d/sec/kg) of body weight.

   a. How much do you weigh? (in pounds) *(Answers will vary.)*

   b. If 1 kilogram (kg) = 2.2 lbs., how much do you weigh in kilograms? *(Answers will vary.)*

$$\frac{1 \text{ kg}}{2.2 \text{ lbs}} = \frac{\text{weight of student in kg}}{\text{weight of student in lbs}}$$

c. Given the activity of potassium-40 above, what is the activity of potassium-40 in your body in disintegrations per second (d/sec)? *(Answers will vary.)*

$$\frac{60 \text{ d/sec}}{1 \text{ kg}} = \frac{\text{activity of potassium (d/sec)}}{\text{weight of student in kg}}$$

Carbon-14

The second largest contributor to our annual internal exposure is carbon-14, a naturally occurring radioactive isotope of carbon. It contributes about 1.2 millirem to our average annual internal radiation exposure.

4. Our bodies are about 23 percent carbon by weight. Because it contains some carbon-14, the carbon in your body has an activity of 227 disintegrations per second per kilogram.

a. Based on your weight in kilograms (from question 3b), how much of your body is carbon? Express your answer in kilograms of carbon. *(Answers will vary.)*

$$\frac{23}{100} = \frac{\text{kg carbon}}{\text{weight of student in kg}}$$

b. Given the activity of carbon-14 in the carbon of your body, what is the total activity of the carbon in your body? *(Answers will vary.)*

$$\frac{227 \text{ d/sec}}{1 \text{kg}} = \frac{\text{activity of carbon (d/sec)}}{\text{weight of carbon in kg}}$$

Carbon, Potassium and Your Health

5. Should you try to eliminate all potassium or carbon from your diet in an effort to reduce your annual internal exposure to ionizing radiation? Why or why not?
(No, you should not. Potassium is important for maintaining the proper pressure and balance within the cells of your body. Potassium is also important for your nerves, muscles, and heart to function properly. Carbon is important in providing the heat and energy necessary for our bodies to function.)

Jet Flight Exposure

Because the atmosphere gets less dense as the elevation increases, the cosmic radiation dose rises with increasing elevation. Therefore, passengers on a jet airplane receive an additional dose from cosmic rays during the flight. According to the National Council on Radiation Protection and Measurements, cosmic exposure at 11,887.20 meters (39,000 feet) is 0.5 millirem per hour.

Directions: Figure the radiation exposure from cosmic radiation for the jet flights listed below.

Flight	Round Trip Flight Time	Radiation Exposure
San Francisco to Washington, DC	12 hours	*(6)* millirem
Atlanta to Chicago	4 hours	*(2)* millirem
Dallas/Ft. Worth to Chicago	4 hours	*(2)* millirem
Boston to Los Angeles	10 hours	*(5)* millirem
Chicago to Honolulu	18 hours	*(9)* millirem
New York to Las Vegas	10 hours	*(5)* millirem

Cosmic Radiation

Cosmic rays originate outside the Earth's atmosphere and are composed of highly penetrating radiation of all sorts, both particles and rays. At sea level, the average annual exposure from cosmic rays is 26 millirem. The following table shows the effect of elevation on cosmic ray exposures.

Effect of Elevation, in Feet, on Cosmic Radiation Exposures (MREM/YR)
(exposures reflect 10% reduction for shielding from buildings/structures)

0 (sea level) ...26	4,000 39
500 27	6,000 52
1,000 28	8,000 74
2,000 31	10,000 107

Directions: Using the data in the table above, calculate the cosmic ray exposure where you live and the exposure from cosmic rays for the cities listed below. (Check an atlas for the elevation above sea level of your area.)

Place	Elevation	Exposures from cosmic rays mrem/yr
Your home town		
Atlanta, GA	1,050	*(28)* millirem
Minneapolis, MN	815	*(28)* millirem
Salt Lake City, UT	4,400	*(42)* millirem
Spokane, WA	1,890	*(31)* millirem

Apollo Flight Exposure

As previously mentioned, U.S. astronauts in Earth orbit or on Moon missions received increased radiation exposure from cosmic rays. The following table shows the estimated exposures by our astronauts on the various Apollo missions. The data are taken from a 1982 report of the United Nations Scientific Committee on the Effect of Atomic Radiation (UNSCEAR) entitled *Ionizing Radiation: Sources and Biological Effects.*

Directions: In the table below, calculate the average rate of exposure in millirem per hour for the various missions.

Estimated Doses Received by Astronauts on the Apollo Missions

Apollo Mission Number	Launch Date	Type of Orbit	Duration of Mission (Hours)	Exposure	
				Total (mrem)	Rate (mrem/hr)
VII	August 1968	Earth orbital	260	120	*(0.46)*
VIII	December 1968	Circumlunar	147	185	*(1.26)*
IX	February 1969	Earth orbital	241	210	*(0.87)*
X	May 1969	Circumlunar	192	470	*(2.45)*
XI	July 1969	Lunar landing	182	200	*(1.10)*
XII	November 1969	Lunar landing	236	~200	*(0.85)*
XIV	January 1971	Lunar landing	286	~500	*(1.75)*
XV	July 1971	Lunar landing	286	~200	*(0.70)*

MANMADE RADIATION SOURCES

1. True or False: In the blank before the sentence, write T if the statement is true and F if it is false. If the statement is false, correct it to make it true.

The following questions are based on the graph titled *Some Exposures from Manmade Sources Compared to the Average Natural Radiation Exposure.*

F a. The exposures from manmade sources shown in the graph are based on the lowest exposures. *(highest)*

T b. The highest exposure to manmade sources of radiation is from smoking cigarettes.

T c. There is more exposure from building materials than from storage of low-level waste.

F d. The only energy use that results in any exposure to radiation is related to nuclear powerplants. *(There is exposure from use of coal and natural gas.)*

2. List 3 consumer goods that are related to radiation exposure.

(cigarettes

lantern mantles

fertilizer, building materials)

3. Write a sentence or two explaining what you think is the source of radioactivity at coal-fired powerplants, construction activities, and fertilizers.

(The source of radioactivity from coal-fired powerplants, construction activities, and fertilizers is the Earth. The radioactivity in rocks and soil is due to the natural presence of potassium - 40 and elements of the uranium and thorium series.)

BIOLOGICAL EFFECTS OF IONIZING RADIATION

Purpose:

The lesson presents the current understanding of the biological effects of ionizing radiation. Students will learn what factors are important in determining the biological effects and what the effects can be. They will gain an appreciation of the difficulties involved in ascertaining or documenting the effects of low-level radiation. They will also gain an appreciation of the limitations of our understanding of the biological effects of ionizing radiation.

Concepts:

1. Ionizing radiation produces chemically active charged and uncharged molecular fragments called ions in material it penetrates, including human tissue.
2. The biological effects of ionizing radiation depend principally on the radiation dose or energy absorbed, the type of radiation, and the type and volume of biological cells exposed.
3. There are two general categories of biological effects from ionizing radiation: somatic effects and genetic effects.
4. Biological effects from exposures to low levels of radiation are usually estimated from effects observed from high radiation doses.
5. No level of radiation exposure greater than zero can be considered completely without risk.
6. Shielding protects individuals and the environment from exposure to ionizing radiation from radioactive materials.

Duration of Lesson:

Two 50-minute class periods

Objectives:

As a result of participation in this lesson, the learner will be able to:

1. name principal factors that determine the biological effects of ionizing radiation;
2. explain the difference between somatic and genetic effects;
3. name some effects of acute exposures to high levels of radiation; and
4. state some reasons why it is difficult to say with certainty what the effect of low levels of radiation is.

Skills:

Reading, discussing

Vocabulary:

Absorbed dose, acute exposure, alpha particle, beta particle, DNA (Deoxyribonucleic acid), gamma ray, genetic effect, gonad, ionizing radiation, millirem, molecule, mutation, rad, radiation, radiation sickness, radiologist, rem, somatic effect, sperm, ultraviolet light, X-ray

Materials:

Reading Lesson

Biological Effects of Ionizing Radiation, p. SR-21

Activity Sheet

Biological Effects of Ionizing Radiation, p. 131

Suggested Procedure:

1. The vocabulary introduced in this lesson is extensive. While many words are defined in the text, it may be helpful to preview the vocabulary words before beginning the reading.

   The class may also find it helpful to page through the reading to see the main sections and to read the questions in the margin to help them focus their reading.

2. Assign the reading entitled *Biological Effects of Ionizing Radiation.*
3. When students have completed the paper and have discussed it, they can review the main points by completing the reading review entitled *Biological Effects of Ionizing Radiation.*
4. The following questions can be used for class discussion.

Sample Discussion Questions:

1. What areas of the human body are more sensitive to radiation than others? Besides the type and volume of cells exposed to radiation, what other factors influence the biological effects of radiation?

   (Organs with rapidly dividing cell systems, such as the bone marrow, gonads, and intestines are more sensitive to radiation.)

   (Radiation dose and type of radiation)

2. What terms are used to describe received doses of radiation? What are acute exposures? What symptoms might be experienced in the hours, days, and weeks after an individual receives an acute exposure of radiation?

   (Rad - radiation absorbed dose)

   (Rem - roentgen equivalent man) (usually millirem)

   (Large doses received over short periods of time are acute exposures.)

   (Symptoms: hours - nausea, headache, appetite loss, diarrhea; weeks - changes in blood cell populations, hemorrhaging, hair loss, infertility and/or sterility)

3. How could you reduce your exposure from a known external source of ionizing radiation?

   (Answers may vary but should include the following: Wear protective clothing. Increase your distance from the source. Stand behind a shield or protective barrier. If you must be near the source, minimize the exposure time.)

4. How would exposure to ionizing radiation be reduced by placing spent fuel in underground geologic formations such as the proposed site at Yucca Mountain, Nevada?

   (Answers will vary. Encourage students to consider the concepts they developed in the question about protection, time, distance and shielding. The appropriate geologic formation has not been disturbed for many years and will continue to be undisturbed. The repository should be placed in an area of low population. The repository will be deep underground distancing it from the surface. The rocks and soil under which the waste is buried also work as a protective barrier shielding the surface from ionizing radiation. The waste will be buried in shielded containers.)

5. The main types of ionizing radiation we are concerned with are alpha and beta particles, gamma rays, and X-rays. Use the illustration showing deposition of energy to discuss how these various types of ionizing radiation interact with human tissue. What does the term "per unit path" mean?

   (Alpha particles have the shortest paths in human tissue and deposit the most energy per unit path. Beta particles travel much farther than alpha particles and deposit less energy per unit path. Gamma rays and X-rays, being waves of pure energy and having no mass, travel very long distances in human tissue, and deposit the least energy per unit path.)

6. It is generally accepted among scientists that natural sources of radiation could account for only 1 to 3 percent of the cancer deaths normally expected in the U.S. population. Using the table "Cancer Deaths Attributed to Various Sources" in the reading lesson titled *Biological Effects of Ionizing Radiation,* discuss the contribution of the various sources to cancer deaths in the United States.

   (a.) Is natural radiation a big cause of cancer compared to other causes?

   (b.) Are food additives a big cause of cancer?

   (c.) What are some things we can do in terms of lifestyle to minimize our risk of getting cancer?

   (The two most important things according to this chart would be to watch diet and avoid smoking. Others relate to sexual lifestyle, occupation, exposures related to our natural environment and pollution.)

7. Some risk of a genetic effect is assumed for even low levels of radiation exposure. In light of this, discuss the following:

   (a.) A woman who is 50 years old has two children, ages 17 and 22. Her doctor told her that it is important for her to have a series of X-rays. She is concerned about possible genetic effects of radiation. Discuss whether she should be.

   (The woman is past ordinary child-bearing age and her children are already born. She cannot pass on a genetic effect to already born children from an event that occurs after they are born.)

(b.) Suppose the woman is 20 years old and has no children. Discuss whether she should be concerned about genetic effects to her children.

(Scientists generally agree that exposure to ordinary diagnostic X-rays is not likely to be harmful. Nevertheless, it is wise for a young woman and her doctor to discuss risks and to weigh the risks and the benefits to be gained from them.)

8. Discuss the following statement: "It is wise for a woman of child-bearing age to determine whether or not she is pregnant before being exposed to ionizing radiation above background levels."

(Again, scientists generally agree that exposure to ordinary diagnostic X-rays is not likely to be harmful. Rapidly dividing cells are especially sensitive to radiation. So prenatal exposures to the developing infant carry some risk. It is important to balance the benefits of the exposure against the risk.)

9. Discuss the role we think the DNA molecules play in determining the effect of radiation on humans. See *DNA: Mighty Molecules* and the diagram of the molecule in *Biological Effects of Ionizing Radiation.*

(There is some indication that ionizing radiation causes cancer or a genetic disorder by radiation damage to the DNA that is passed on to a great many cells when the cell containing the damaged DNA divides. However, exactly how radiation or other agents cause such effects is not completely understood.)

10. Some effects of exposure to ionizing radiation are delayed and don't show up for many years. Why does this make it difficult to determine exactly what the effects of exposures to low levels of ionizing radiation are?

(The negative health effects of low exposures to ionizing radiation, if there are any, take decades to develop. There are also no observable differences between the negative health effects from radiation and those from many other agents. Therefore, a causal relation between low radiation exposures and a delayed health effect in humans is hard to establish definitively.)

11. There is little data on the effects of exposures to low levels of radiation to examine. Instead scientists rely on information gained from data about high exposures or on data from studies with animals, chiefly mice. Discuss how these two facts affect uncertainty about effects of low exposures.

(There is also disagreement among scientists about whether the data from low-exposure studies with animals can be applied to humans. As in Question 10 above, for humans the many years delay between exposures and effects leads to uncertainties as to a causal relationship.

Scientists agree, however, that low exposures spread over weeks or months have a much lower effect than the total exposure given all at once.)

12. The human species has always been exposed to natural radiation. Some scientists speculate that this may mean there may be some beneficial effects of ionizing radiation. What do you think about this idea?

    (Answers will vary.)

The section of the reading lesson entitled *Ionizing Radiation and Cancer* describes the relationship between radiation exposure and cancer. Generally, this section suggests that the risk of cancer increases as exposure to radiation increases. A study supporting results to the contrary may be interesting for your students to read. The article entitled, "A search for latent radiation effect among men who served as x-ray technologists in the U.S. Army during World War II", can be found in Radiology (1970), Volume 96, pages 269-274. In this study, cause of death for men trained as radiological technologists by the U.S. Army during W.W. II were compared to men trained as pharmacy or medical laboratory technologists. No significant differences in leukemia rate existed.

Teacher Evaluation of Learner Performance:

Student participation in class discussion and completion of activity will indicate understanding.

BIOLOGICAL EFFECTS OF IONIZING RADIATION

Ionizing radiation can cause damage to living tissue. Scientists generally agree on the effects of high levels of exposure. But there is disagreement about the effects of low levels of exposure.

2.20 Introduction

What factors determine the effects of radiation on the body?

Because ionizing radiation is high energy radiation which can knock electrons out of atoms and molecules, it can damage human tissue. The effects of ionizing radiation on the body depend on many things. First and most important, how much radiation energy was absorbed by the body? Second, what type of radiation was it? Third, what kind of cells—and how many of them—were exposed?

Is there a threshold for risk?

It was once thought that there might be a radiation exposure so low that there would be no risk associated with it. The risk of injury does decrease with decreasing exposure. But, while there may be very little likelihood of injury from exposures to low levels of radiation, some degree of risk is assumed when people are exposed to even very small amounts of radiation.

What can happen when radiation strikes a cell?

The damage done by radiation results from the way it affects *molecules* essential to the normal function of body cells. Four things may happen when radiation strikes a cell: 1) It may pass through the cell without doing any damage. 2) It may damage the cell, but the cell repairs the damage. 3) It may damage the cell so that the cell not only fails to repair itself but reproduces itself in damaged form over a period of years. 4) It may kill the cell. The death of a single cell may not be harmful, but serious problems occur if so many cells are killed in a particular organ that the organ no longer can function properly. Over time, incompletely or incorrectly repaired cells may produce delayed health effects such as cancer or genetic *mutations* or birth defects in babies exposed prior to birth.*

*Source: Primer on Radiation, *FDA Consumer (HEW Publication No.)* (FDA) 79-8099.

What is the effect of exposure time?

Longer exposures to radiation increase the chance that damage will occur. However, if enough time passes between exposures, a higher total exposure may be tolerated than if the total exposure is received all at once. This effect is similar to the body's response to solar radiation — too much sun can cause a severe sunburn, but short exposures and sun block can limit the sun's burning effect on the skin.

Longer exposures to ionizing radiation allow some of the damaged cells to be repaired by the body, helping to reduce the overall effect. A damaged area may also be healed by healthy cells from an area not exposed to radiation. Radiation damage to **large** numbers of cells may be partially repaired, but some damage is permanent.

Does the amount of tissue exposed matter?
What cells are more sensitive to radiation?

The more tissue exposed to radiation, the greater the chance of injury. Exposure of the whole body, for instance, presents more risk than exposure of an arm or leg or single organ to the same radiation. Also, organs differ in how sensitive they are to radiation, so the type of cells exposed makes a difference. Rapidly dividing cells are generally more sensitive.

Tissue Sensitivity

Some cells, tissues, and organs are significantly more sensitive to radiation than others. Generally, organs with rapidly dividing cell systems, such as the bone marrow, gonads, and intestines, are more sensitive than non-dividing systems like the kidneys, liver, and brain. Cells that perform specialized functions are less sensitive than those that do not.

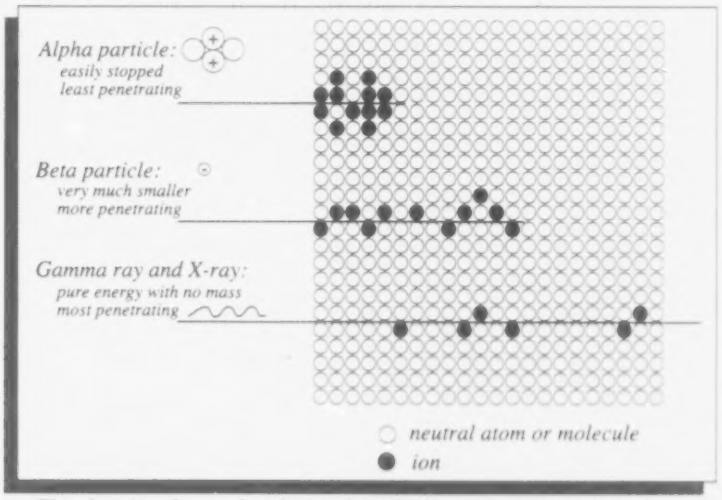
How do the types of radiation differ in the way they deposit energy?
What are some properties of alpha radiation?
What are some properties of beta radiation?

The type of radiation is also important. Alpha, beta, and gamma radiations differ in both their abilities to penetrate tissue and in the likelihood that they will cause biological damage. Alpha particles are large and carry a double positive charge. They travel only a short distance in living tissue, but they deposit all their energy in that short path. This increases the likelihood that they will cause damage. Beta particles carry a single negative charge and are thousands of times smaller than alpha particles. They travel longer distances in living tissue than alpha particles, but deposit their energy over a longer path. For this reason, they are less likely to cause damage. Because alpha

and beta particles are not very penetrating, they mainly damage skin and surface organs. However, they can affect internal organs if substances giving off alpha and beta radiation are swallowed or inhaled.

Gamma rays and X-rays have similar properties, but gamma rays are generally more energetic. Their biological effects are similar. Their paths in living tissue are long. This means their energy is deposited over a longer path and is less likely to cause damage. But because they can penetrate the body more deeply, they can affect internal organs.

What are some properties of gamma and X-rays?



This drawing shows what the "paths" of different types of radiation might look like. Ions are formed when a particle, gamma ray, or X-ray penetrates tissue. Because alpha particles deposit all their energy along a short path, they are more likely to cause damage.

Source: Adapted from Radiation Activities for Youth Series, *copyright The Pennsylvania State University, Nuclear Engineering Department, 1988. Permission for use granted.*

2.21 Measuring Potential Health Effects

The basic unit for measuring radiation received is the *rad* (radiation absorbed dose). One rad equals the absorption of 100 *ergs** in every gram of tissue exposed to radiation.

How do we measure radiation exposure?

To show biological risk, rads are converted to *rems*. The rem is adjusted to take into account the type of radiation absorbed and the differences in likelihood of damage from the different

How do we estimate biological risk from exposure?

**erg - a small but measurable amount of energy (See glossary)*

types of radiation. But exposures are normally fractions of a rem, so the commonly used unit is the *millirem*.

$$1 \text{ millirem} = \frac{1}{1{,}000} \text{ of a rem}$$

2.22 Biological Effects

What are somatic effects?

There are two categories of effects from ionizing radiation: *somatic effects* and *genetic effects*. Somatic effects appear in the exposed person. They result from radiation damage to body cells that are **not** reproductive cells. They can occur soon after the exposure or they can take a number of years to become obvious. Somatic effects cannot be inherited.

What are genetic effects?

Genetic effects may appear in children conceived after a parent has been exposed to radiation if that parent's egg or sperm cells were affected. Genetic defects can be inherited.

What are the effects of acute exposures?

Large exposures in short periods of time (acute exposures) produce injuries within weeks or even hours. The severity depends on the amount of radiation received. For example, 100,000 to 400,000 millirem, could cause *radiation sickness*. An exposure of 400,000 to 500,000 millirem within a short period of time, if left untreated, has a 50 percent chance of causing death in a population. An exposure of 500,000 millirem is nearly 1,500 times the 360 millirem exposure the average American receives from all sources in a year.

What is Radiation Sickness?

Acute exposure ranging from 100,000 to 400,000 millirem can result in any and/or all of the following effects.

Within hours or weeks: nausea, headache, loss of appetite, changes in blood cells.

Within succeeding weeks: loss of hair, hemorrhaging, diarrhea, effects on the central nervous system.

In most cases, prompt medical treatment gradually restores the patient's health.

Even larger exposures can destroy bone marrow cells. (This happened to some victims of the Chernobyl nuclear reactor accident in the Soviet Union in the 1980s). Bone marrow transplants have been used to treat people exposed to large amounts of radiation, but results depend upon exposure and individual variations.

What are the effects of low exposures?

Exposure to low amounts of radiation (1,000 millirem or less) produces no observable effect. Larger exposures received over weeks or months may not produce visible symptoms. There is a slight risk, however, that a delayed effect (such as cancer) could develop 10 to 40 years later. It's also possible (but even less likely) that damage to a reproductive cell could have occurred.

2.23 Ionizing Radiation and Cancer

How do we know ionizing radiation can cause cancer?

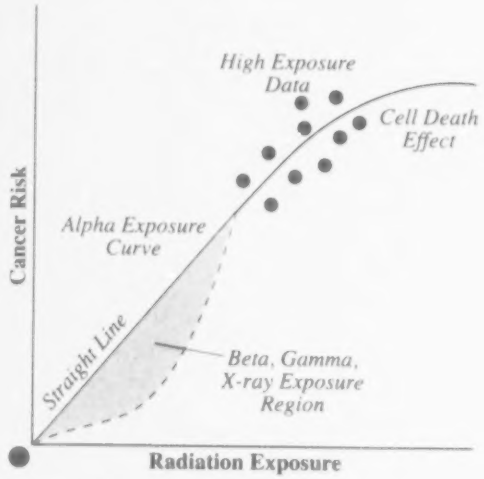
Based on the cancer death rate of groups of people exposed to **large** amounts of ionizing radiation, we know that it can cause cancer. The most significant groups are 1) survivors of the atomic bombs dropped on Japan; 2) U.S. *radiologists* who used ionizing radiation from the 1920's through the 1940's to diagnose and treat medical problems; and 3) people given high X-ray exposures to treat a disease of the spine in the early days of radiation treatments.

Why are we concerned about low levels of ionizing radiation?

No direct data exists to estimate the risk of death from cancer caused by low levels of ionizing radiation, such as we receive from our natural environment. Scientists agree on effects from high levels of exposure. But there is disagreement about effects of low levels of exposure. There is uncertainty about effects of low exposures because there is no direct data, and conclusions have to be made on the basis of information we have gathered about cancer deaths from high exposures.

As you can see in the graph, risk of cancer death decreases as exposure to high levels of radiation decreases. The straight line drawn through the high exposure data down to zero is assumed to show fairly well the cancer death risks from low levels of exposure to alpha radiation. The effects of low exposures to beta, gamma, and X-ray radiation are more uncertain, as shown by the gray area of the graph.

Effects of low exposures to beta particles, gamma rays, or X-rays could be 2 to 10* times less than what would be predicted by the straight line.



Cancer Risk versus Radiation Exposure: A straight line drawn to zero exposure through data of high exposures is believed to estimate the effects of low exposures of alpha radiation. The effects of low exposures of beta, gamma, or X-ray radiation could be 2 to 10 times less than would be predicted by the straight line.

* *Source: United Nations Scientific Committee on the Effects of Atomic Radiation:* Sources, Effects and Risks of Ionizing Radiation, *1988.*

Many things cause cancer, including ultraviolet light, smoking tobacco, asbestos, and certain pesticides and many other chemicals. Statistics show that 17 percent of the people

Cancer Deaths Attributable to Various Sources[a]

Source	Cancer Deaths, Percent
Diet	35 [b]
Tobacco	30 [b]
Infection	10 [c]
Sexual lifestyle	7 [b]
Occupation	4
Alcohol	3
Natural environment	3 [d]
Pollution	2
Medical care	1
Food additives	1
Industrial products	1
Unknown	—

[a] Adapted from R. Doll and R. Peto, *Journal of the National Cancer Institute*, vol. 66, 1981.
[b] Ranges of possible percentages:
Diet, 10-70; Tobacco, 25-40; Sexual lifestyle, 1-13
[c] Speculative; range not estimated
[d] Includes background radiation
[e] Sources of some common cancers unknown (e.g., prostate, bone marrow, lymph tissue); psychological contributions (such as stress) not identified

(170,000 out of 1 million) in the United States die from cancer from all causes. As you already know, average annual exposure for people living in the United States is about 300 millirem from **natural** sources. It is generally accepted among scientists that from one to three percent of all cancer deaths could be the result of this yearly exposure.

2.24 Effects on the Unborn

Why is it hard to estimate how radiation affects an unborn child?

Many genetic and environmental factors affect development of babies before birth. For this reason, it is difficult to say with certainty how radiation exposure affects an unborn child. Therefore, information gathered from animal studies is generally used to estimate these effects.

Animal studies have shown that exposure can result in a very wide range of results—from no observable damage to malformations of major organs of the body, slowed growth, damage to the central nervous system, and even death. Effects vary depending on the stage of development at the time of exposure and the level of exposure. Since experimental studies are not conducted on humans, the major sources of information about effects on humans are survivors of the atomic bombs in Japan and patients exposed during medical diagnosis or treatment. The most commonly reported abnormalities are defects to the central nervous system and slowed growth.

What data on humans is available?

Rapidly dividing cells are especially sensitive to radiation. So, before birth and during infancy when children grow rapidly, medical exposures to radiation carry a risk. Scientists generally agree that exposure to ordinary diagnostic X-ray is **not** likely to be harmful. Nevertheless, it is important to balance benefits of exposure to radiation against risks. It is wise for a woman of child-bearing age to determine whether or not she is pregnant before being exposed to radiation above background levels. This precaution can help avoid unnecessary risk.

2.25 Birth Defects: A Fact of Life

Approximately 10 percent of all children born (100 thousand out of a million) have some genetic defect. These defects range from those so mild they are never noticed to those that are severe and even fatal. Spontaneous defects occur when unknown factors cause cells to not work properly. Defects may also occur because cells are affected by something in the environment, including ionizing radiation.

How common are birth defects?

Genetic effects are effects that are inherited by the offspring of an individual whose egg or sperm cells have been damaged. No hereditary defects caused by ionizing radiation have been observed in humans, even among Japanese survivors of the atomic bombs. However, there is enough data from laboratory studies (most often using mice) to predict such effects.

Have genetic defects from radiation been observed in humans?

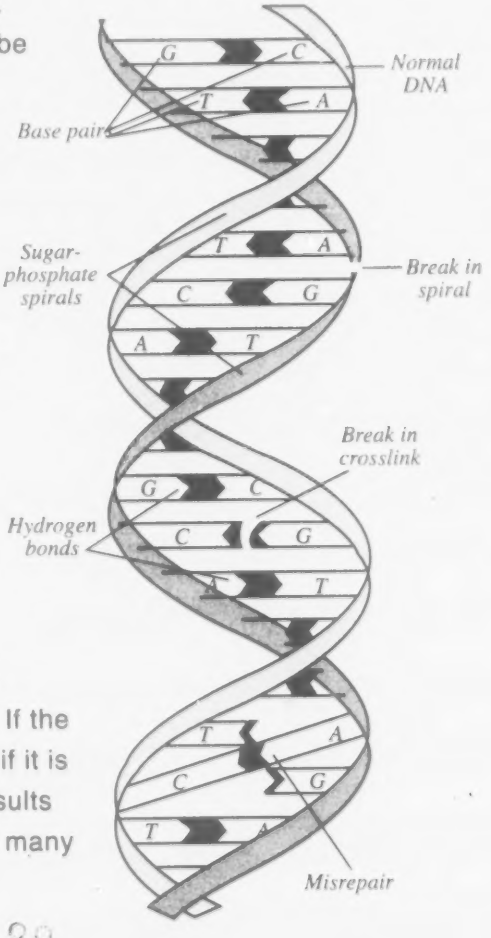
2.26 DNA: Mighty Molecules

What is DNA? Why are they important?

Our bodies are made up entirely of cells. You were formed—and continue to grow—because cells continue to divide and reproduce themselves. Very large molecules in our cells determine what types of cells will form, making us what and who we are. These molecules are called *DNA*, which stands for *deoxyribonucleic acid*.

What kinds of damage can happen to DNA?

Take a close look at the drawing of a DNA molecule. Notice that the top section shows a normal, healthy arrangement. The second and third sections, on the other hand, show two different types of damage to DNA. The second section shows the most common type of injury, a break in the spiral. The third section contains a break in one of the crosslinks. The fourth section illustrates how the body might incorrectly repair a crosslink. An abnormality like this can be passed on to many cells.



Our bodies are composed of **billions** of cells. It's not surprising, then, to learn that damage to DNA occurs all the time. For the most part, our bodies simply go about their business of repairing damage. DNA repair does take a certain amount of time, however, and too much injury within a given time can overwhelm the ability of the body to repair the damage. If the damage is not repaired—or if it is repaired incorrectly—the results are passed along to a great many cells.

One of the many causes of damage to DNA is ionizing radiation. Low exposures usually do not affect the body's ability to repair damage. But high levels of exposure can damage such a large number of DNA molecules that repair (or proper repair) is less likely. This increases the possibility of harmful health effects.

There is some indication that radiation causes cancer by a DNA defect or incorrect repair. However, exactly how radiation or any other cancer-causing agents cause cancer is still not completely understood. It is also uncertain whether low exposures to ionizing radiation cause cancer. However, because we cannot prove that there is no effect, some small risk is assumed for any low level of exposure greater than zero.

What is the possible effect of damage to DNA?

Genetic disorders are also related to defects in DNA. But many things may cause genetic disorders, and many disorders caused by radiation can't be distinguished from those with other causes. Nevertheless, as with cancer, some small risk is assumed for any level of radiation exposure.

BIOLOGICAL EFFECTS OF IONIZING RADIATION

Refer to the reading entitled *Biological Effects of Ionizing Radiation* to answer the questions below.

1. The principle factors that determine the biological effect of ionizing radiation are _____
(radiation dose, type of radiation, type and volume of biological cells exposed)

2. The possibility of injury from ionizing radiation _____*(increases)*_____ with increasing exposure.

3. Increasing the volume of tissue exposed _____*(increases)*_____ the severity of radiation injury.

4. Alpha particles deposit all their energy in a _____*(short)*_____ path.

5. X-rays and gamma rays deposit their energy over a _____*(longer)*_____ path.

6. The two main categories of biological effects are _____*(somatic)*_____ effects and _____*(genetic)*_____ effects.

7. Of the two main types of effects in question 6, which applies to the exposed individual and which applies to future generations?

   _____*(somatic)*_____ effects apply to the exposed individual

   _____*(genetic)*_____ effects apply to future generations

8. Background radiation accounts for only _____*(1)*_____ to _____*(3)*_____ percent of the spontaneous incidence of cancer.

9. The _____*(unborn)*_____ and _____*(newborn)*_____ are particularly sensitive to radiation exposure.

10. For any radiation exposure greater than zero, there is some _____*(risk)*_____ .

USING HALF-LIVES

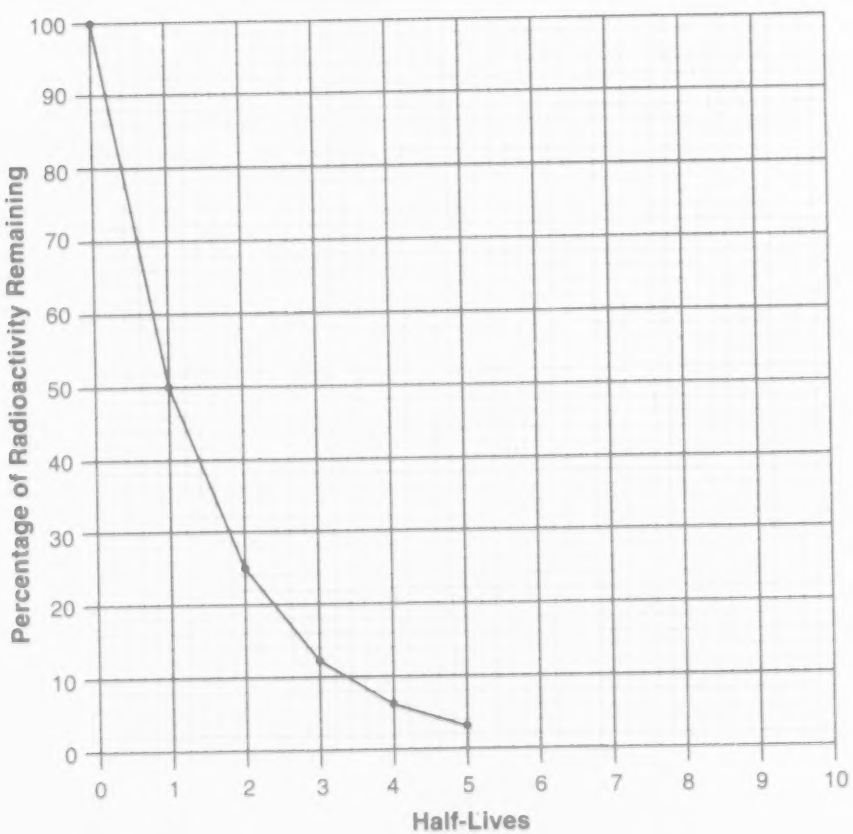
Radioactive materials spontaneously emit ionizing radiation during the process of radioactive decay and become less radioactive over time as a result of this process. The time required for a quantity of a radioactive substance to lose half its radioactivity by radioactive decay is the half-life of that substance. Half-life is a unique characteristic of each radioisotope.

Directions: Answer the following questions by applying the information about half-life given above. Read carefully and think before answering.

1. What percentage of the original radioactivity of a quantity of a radioactive material remains after each half-life?

0	1	2	3	4	5
100%	*50%*	*25%*	*12.5%*	*6.25%*	*3.125%*

2. Plot the radioactive decay curve from data in Question 1. On the x-axis plot half-lives and on the y-axis the percentage of radioactivity remaining. Connect each point with straight line segments.



3. Radium has a half-life of 1600 years. Approximately, how long does it take for 1 percent of a sample of radium to decay?

Method 1

{If 50% decays in 1600 years then 1% decays in how many years?}

$$\frac{50\%}{1600 \text{ years}} = \frac{1\%}{x \text{ years}} \qquad \textit{(set up a proportion)}$$

$$(50\%)(x \text{ years}) = (1\%)(1600 \text{ years}) \qquad \textit{(cross multiply)}$$

$$\frac{(50\%)(x \text{ years})}{50\%} = \frac{(1\%)(1600 \text{ years})}{50\%} \qquad \textit{(solve for x)}$$

$$x = 32 \text{ years}$$

Method 2

$$\frac{1}{50}(1600) = 32 \text{ years}$$

4. Radon has a half-life of 3.8 days. Approximately, how long does it take for 1 percent of a sample of radon to decay? Express your answer in hours.

Method 1

$$\frac{50\%}{3.8 \text{ days}} = \frac{1\%}{x \text{ days}}$$

$$\frac{(50\%)(x \text{ days})}{50\%} = \frac{(1\%)(3.8 \text{ days})}{50\%}$$

$$x = 0.076 \text{ days}$$

$$\frac{1 \text{ day}}{24 \text{ hours}} = \frac{0.076 \text{ days}}{x \text{ hours}}$$

$$\frac{(1 \text{ day})(x \text{ hours})}{1 \text{ day}} = \frac{(0.076 \text{ days})(24 \text{ hours})}{1 \text{ day}}$$

$$x = 1.82 \text{ hours}$$

Method 2

$$\frac{1}{50}(3.8)(24) = 1.82 \text{ hours}$$

5. Scientists believe the Earth is 4.6 billion years old

   a. Approximately what percentage of the uranium-238 originally present is here now if the half-life of uranium-238 is 4.5 billion years?

   approximately 50%

   b. Calculate a more exact percentage.

$$\text{Number of half-lives elapsed} \quad (H) = \frac{\text{Elapsed Time}}{\text{Half - Life}}$$

$$H = \frac{4.6 \text{ billion years}}{4.5 \text{ billion years}}$$

$$H = 1.022$$

This represents one half-life plus 0.022 of the second half-life. After 1 half-life, 50% has decayed and 50% remains. Remember that after 2 half-lives, 25% of the original radioactivity remains. The answer is between 50% and 25%. Calculate on the 50% remaining after one half-life.

Method 1

$$\frac{25\% \text{ will decay}}{1 \text{ half-life}} = \frac{x\% \text{ will decay}}{0.022 \text{ half-lives}}$$

$$\frac{(25\%)(0.022 \text{ half-lives})}{1 \text{ half-life}} = \frac{(x\%)(1 \text{ half-life})}{1 \text{ half-life}}$$

$$0.55\% = x$$

$$50\% - .55\% = 49.45\% \text{ remaining}$$

Method 2

Percent left after 1.022 half-lives

$$50\% - (0.022)(25\%) = 49.45\%$$

6. Calculate approximately what percent of the original thorium-232 is left if it has a half-life of 14 billion years.

Method 1

$$H = \frac{4.6 \text{ billion years}}{14 \text{ billion years}} = 0.329 \text{ half-lives (one half-life has not been completed)}$$

In the first completed half-life 50% of the original amount of thorium-232 will decay.

$$\frac{50\%}{1 \text{ half-life}} = \frac{x\%}{0.329 \text{ half-lives}}$$

$$\frac{(50\%)(0.329 \text{ half-lives})}{1 \text{ half-life}} = \frac{(x\%)(1 \text{ half-life})}{1 \text{ half-life}}$$

$$16.45\% = x$$

$$100\% - 16.45\% = 83.55\% \text{ remaining}$$

Method 2

$$\text{Number of half-lives} = \frac{4.6}{14} = 0.329$$

$$100\% - (0.329 \times 50\%) = 83.55\%$$

7. Uranium-235 has a half-life of 0.7 billion years and also was present when the Earth was formed.

   a. How many U-235 half-lives have occurred since the beginning of the Earth?

$$H = \frac{4.6 \text{ billion years}}{0.7 \text{ billion years}}$$

$$H = 6.57 \text{ half-lives}$$

   b. Approximately what percent of the original uranium-235 is left?
   (Hint: Make a table of half-lives and calculate the fraction remaining after each half-life.)

Half-lives	1	2	3	4	5	6	7
Fraction Remaining	1/2	1/4	1/8	1/16	1/32	1/64	1/128

By the sixth half-life 1/64th or 2/128th of the original U-235 remains.
In this problem 0.57 of those 2/128ths will decay.

$$\frac{2}{128} - \frac{.57}{128} = \frac{1.43}{128}$$

$$\frac{1.43}{128} = \frac{x}{100} \quad \text{(Change to a percent.)}$$

$$\frac{(1.43)(100)}{128} = \frac{(128)(x)}{128}$$

$$1.12\% = x$$

This problem can also be answered using percentages.

Half Lives	1	2	3	4	5	6	7
Percentage Remaining	50%	25%	12.5%	6.25%	3.13%	1.56%	0.78%

By the sixth half-life 1.56% of the original U-235 remains. During the sixth half-life 0.78% of the original amount will decay.

$$\frac{0.78\%}{1 \text{ half-life}} = \frac{x\%}{0.57 \text{ half-lives}}$$

$$\frac{(0.78\%)(0.57 \text{ half-lives})}{1 \text{ half-life}} = \frac{(1 \text{ half-life})(x\%)}{1 \text{ half-life}}$$

$$0.44\% = x$$

$$1.56\% - 0.44\% = 1.12\%$$

8. All natural uranium contains both U-235 and U-238. Each decays at a different rate but both are always present in any quantity of natural uranium. We must consider changes in both U-235 and U-238 to calculate the concentration of either at any given time. Keep in mind that natural uranium = U-235 + U-238.

   a. Today, natural uranium contains about 0.7% U-235. How much U-238 does natural uranium contain today?

   $$\underset{\text{(Nat. U)}}{100\%} - \underset{\text{(U-235)}}{0.7\%} = \underset{\text{(U-238)}}{99.3\%}$$

   b. The percentages from (a.) are true for any unit of natural uranium. Consider one gram of natural uranium today. What fractional portion of U-235 and of U-238 would comprise that one gram of natural uranium?

   (The choice of one gram as a measure of mass is completely arbitrary. Any mass—one pound, two ounces, etc.—would produce the same answer.)

   $$\text{U-235} \quad \frac{0.7\%}{100\%} = \frac{x \text{ grams}}{1 \text{ gram}}$$

$$0.007 \text{ grams} = x$$

$$\text{U-238} \quad \frac{99.3\%}{100\%} = \frac{x \text{ grams}}{1 \text{ gram}}$$

$$0.993 \text{ grams} = x$$

c. How much U-235 was required 4.6 billion years ago to produce 0.007 grams of U-235 in every gram of natural uranium today? Remember that 1.1% of the total amount of U-235 remains undecayed today. (Question 7b)

$$\frac{0.007 \text{ grams U-235 today}}{1.1\% \text{ of original amount}} = \frac{x \text{ grams U-235 4.6 billion years ago}}{100\% \text{ of original amount}}$$

$$0.636 \text{ grams U-235} = x$$

d. How much U-238 was required 4.6 billion years ago to produce 0.993 grams of U-2238 in every gram of natural uranium today? Remember that 49.45% of the total amount of U-238 remains undecayed today. (Question 5b)

$$\frac{0.993 \text{ grams U-238 today}}{49.45\% \text{ of original amount}} = \frac{x \text{ grams U-238 4.6 billion years ago}}{100\% \text{ of original amount}}$$

$$2.008 \text{ grams U-238} = x$$

e. Keeping in mind that natural uranium = U-235 + U-238, what percent of U-235 existed in natural uranium 4.6 billion years ago?

$$\frac{0.636 \text{ grams U-235}}{0.636 \text{ grams U-235} + 2.008 \text{ grams U-238 (natural uranium)}} = \frac{x\%}{100\%}$$

$$24.05\% = x$$

9. Based on evidence discovered in 1972, scientists believe that about 2.0 billion years ago, a fission chain reaction occurred spontaneously at Oklo, Gabon, in Africa. Remember that natural uranium = U-235 + U-238 and that U-235 at some concentration was necessary for this reaction to occur. Answer the following to determine the concentration of U-235 in natural uranium 2.0 billion years ago.

a. How much time had elapsed since the formation of the Earth 4.6 billion years ago when the reaction at Oklo occurred?

$$4.6 \text{ billion years} - 2.0 \text{ billion years} = 2.6 \text{ billion years}$$

b. At the time of the Oklo reaction, how many half-lives of U-235 and of U-238 had elapsed?

$$H\ U\text{-}235 = \frac{2.6}{0.7} = 3.71 \text{ elapsed}$$

$$H\ U\text{-}238 = \frac{2.6}{4.5} = 0.58 \text{ elapsed}$$

c. What percentage of the original amount of U-235 and U-238 remained at the time of the nuclear reaction in Oklo, Gabon?

U-235 - By the third half-life 1/8th or 2/16ths of the original U-235 remains. In this problem 0.71 of those 2/16ths will decay.

$$\frac{2}{16} - \frac{0.71}{16} = \frac{1.29}{16} = 0.08 \qquad 0.08 \times 100 = 8\%$$

U-238- At the beginning of the first half-life 1/1 or 2/2 of the original U-238 remains. In this problem 0.58 of those 2/2 will decay.

$$\frac{2}{2} - \frac{0.58}{2} = \frac{1.42}{2} = 0.71 \qquad 0.71 \times 100 = 71\%$$

d. 4.6 billion years ago natural uranium was 24.05% U-235. (Question 8). What percent of natural uranium was U-238?

$$\underset{\text{(Natural Uranium)}}{100\%} - \underset{\text{(U-238)}}{24.05\%} = 75.95\%$$

e. Consider one gram of natural uranium 4.6 billion years ago. What fractional portion of U-235 and U-238 would comprise that one gram?

$$U\text{-}235 \quad \frac{24.05\%}{100\%} = \frac{x\ g}{1g}$$

$$0.2405 \text{ grams } U\text{-}235 = x$$

$$U\text{-}238 \quad \frac{75.95\%}{100\%} = \frac{x\ g}{1g}$$

$$0.7595 \text{ grams } U\text{-}238 = x$$

f. If the one gram of natural uranium from (e.) were to decay until the time of the Oklo reaction, how many grams of U-235 and U-238 would remain?

$$\text{U-235} \quad - \quad \frac{0.2405 \text{ grams U-235}}{100\%} = \frac{x \text{ grams U-235}}{8\%}$$

$$0.019 \text{ grams U-235} = x$$

$$\text{U-238} \quad \frac{0.7595 \text{ grams U-238}}{100\%} = \frac{x \text{ grams U-238}}{71\%}$$

$$0.539 \text{ grams U-238} = x$$

g. Keeping in mind that natural uranium = U-235 + U-238, what percent of U-235 existed in natural uranium at the time of the Oklo reaction?

$$\frac{0.019 \text{ grams U-235}}{(0.539 \text{ grams U-238} + 0.019 \text{ grams U-235})} = \frac{x\%}{100}$$

$$3.4\% = x$$

Note: Fuel used in nuclear powerplants in the United States is approximately 3-4% uranium-235.

The Oklo reactor consumed about 6 tons of U-235 over hundreds of thousands of years. A large light water reactor (LWR) powerplant (1000 megawatts electric) consumes about one ton of U-235 every year.

RADIOACTIVE DECAY SERIES

Purpose:

This lesson will demonstrate for students that ionizing radiation is a part of nature and our natural environment, that it can result from human activity, and that radioactive materials spontaneously emit radiation during the process of radioactive decay.

Concepts:

1. Radioactivity is a fact of life on Earth and not necessarily the product of the nuclear age.
2. Radioactive chemical elements emit radiation in the form of alpha or beta particles and are transformed into other elements.
3. The emission of a gamma ray often accompanies alpha or beta decay.
4. There are three naturally occurring decay series beginning with the uranium-238, uranium-235, and thorium-232 that were present when the Earth was formed.

Duration of Lesson:

One 50-minute class period

Objectives:

As a result of completion of *Radioactive Decay Series* activities, the learner will be able to:

1. identify the atomic transitions occurring in a natural series;
2. identify the sources of the radioactive elements (i.e., "daughter products") in the naturally occurring decay series;
3. plot the atomic transitions in a chart of the nuclides; and
4. read and prepare a table from a chart of atomic transitions.

Skills:

Completing charts and tables, discussing, drawing conclusions, interpreting data from charts and tables, reading comprehension

Vocabulary:

Alpha particle, atom, beta particle, emit, gamma ray, nuclear radiation

Materials:

Reading Lesson

Radioactivity Review, p. SR-31

Activity Sheets

Atomic Transitions in the Natural Radioactive Decay Series, p. 139

Chart of the Isotopes in the U-238, U-235, and Th-232 Decay Series — Thorium-232 Series, p.141; *Uranium-235 Series*, p.143; *Uranium-238 Series*, p. 145

Transparencies

Chart of the Isotopes in the U-238, U-235, and Th-232 Decay Series (Thorium-232 Series), p. 137

Background Notes

Presenting Information on Radioisotopes: The "Chart of the Nuclides", p. 65

Suggested Procedure:

1. Before beginning the activity, a review of the structure of the atom, atomic number, and atomic weight may be helpful. These terms are discussed in the reading lesson entitled *Radioactivity Review*. Students should read the lesson that introduces the activity entitled *Radioactive Decay Series* and discuss alpha and beta decay thoroughly before proceeding.
2. Students should use the table of the atomic transitions in the Th-232 series and trace the plot of the transitions on the chart. It is recommended that this be done as a group activity.

Note: In the thorium decay series, when a bismuth-212 nucleus decays, it may emit either an alpha particle or a beta particle, but not both. Statistically, 66.3% emit a beta particle and 33.7% emit an alpha particle. This happens in other series, but the percentages are not usually this close; usually only a small percentage are "mavericks."

3. Using the table of transitions in the uranium-235 decay series, students should plot the transitions in the uranium-235 decay series on their chart.
4. Using the plot of the uranium-238 series on the chart, have students complete the table of the transitions in the uranium-238 series.

Sample Discussion Questions:

1. We say that an atom is the smallest part of matter that retains all chemical characteristics of an element. What do we mean when we talk about the chemistry of an element?

   (Basically, the chemistry is the way the atom interacts with other atoms to form combinations or compounds. The interaction is dependent on the electrons in the atom.)

2. Isotopes of different elements may have the same atomic weight. What makes them different?

   (Atomic number, which is the number of protons)

3. What are the numbers at the left of the elements on the chart of the isotopes?

   (Atomic number/number of protons)

4. What are the numbers at the bottom of each box?

   (The number of neutrons)

5. As a result of alpha decay, what happens to the atomic number and atomic weight?

   (Goes down 2 in atomic number; atomic weight goes down 4)

6. As a result of beta decay, what happens to the atomic number and atomic weight?

   (Goes up 1 in atomic number; atomic weight stays the same)

7. At the end of each decay series in the column for type of decay is the word stable. What does stable mean?

   (A stable isotope is not radioactive and does not undergo radioactive decay. Each of the natural decay series ends in some isotope of lead.)

Teacher Evaluation of Learner Performance:

Verbal response of students in discussion and written response on activity sheets will indicate comprehension.

Student response to sample discussion questions will indicate an ability to interpret the data entered on student activity sheets.

PRESENTING INFORMATION ON RADIOISOTOPES: THE *CHART OF THE NUCLIDES*

The activities in the *Radioactive Decay Series* require students to use "stairstep" charts to plot the atomic transitions occurring in the natural radioactive decay series and in spent fuel. These charts introduce students to a device they may not be familiar with that presents information on radioisotopes and radioactive decay. They are adapted from sections of a more general presentation called the *Chart of the Nuclides*. The *Chart of the Nuclides* presents the most pertinent information on all known radioactive and non-radioactive isotopes in a way that makes it relatively easy to follow the atomic transitions resulting from radioactive decay. It also gives the half-lives of the radioisotopes and the energies associated with the decay.

The *Chart of the Nuclides* is similar to the *Periodic Table of the Elements* in that it organizes and arranges information to give scientists both a quick overview and important detailed information. The periodic table was developed before radioactivity was discovered and before the isotopic nature of the chemical elements had become known. The periodic table presents in convenient form the periodicity or repetition of chemical behavior with increasing atomic number. For example, lithium, sodium and potassium with atomic numbers 3, 11 and 19, respectively, are similar in their chemical properties. Likewise fluorine, chlorine, and bromine with atomic numbers 9, 17 and 35, respectively, have common characteristics, differing mainly in degree of reactivity. The periodic table aided in the search for chemical elements then unknown by predicting their properties and encouraged research in the structure of atoms and how electrons are arranged around nuclei in a manner that makes the chemical behavior of the elements understandable and predictable. Although there have been many refinements to Mendeleev's original 1869 formulation, the fundamental principles leading to the tabulation remain the same today. The periodic table is of primary interest to chemists, both practical and theoretical.

The *Chart of the Nuclides* is a product of the atomic age. The necessity for such a tabulation arose from the production and isolation of large numbers of radioisotopes following the development of the atomic bomb and a concurrent large increase in our knowledge of radioactivity. The need for an ordered formulation of isotopic information was further enhanced by the initiation of nuclear power development, the increased interest in isotopes (both radioactive and non-radioactive), and the realization of the enormous benefits that could be realized in all areas of human endeavor from the use of isotopes. The *Chart of the Nuclides* has a more universal appeal than the *Periodic Table of the Elements* and is of practical use in nearly all technical disciplines.

The chart was developed in the latter forties at the Knolls Atomic Power Laboratory operated by the General Electric Company under the direction of what was then the U.S. Atomic Energy Commission and is now the U.S. Department of Energy. The chart has gone through many revisions since it was first developed. The present arrangement is similar to that suggested in the beginning by Emilio Segre. The current chart reflects isotopic data up to the middle of 1983.

The chart is called the *Chart of the Nuclides* rather than the "Chart of the Isotopes" because *nuclide* is a more general term than *isotope*. *Nuclide* is a term applicable to *all* atomic forms of *all* the chemical elements. *Isotope* is a more restrictive term and refers to the various atomic forms of a single chemical element. The isotopes of a single chemical element may be thought of as a "family" of nuclides.

The *Chart of the Nuclides* can be purchased as a 55" x 32" wall chart and booklet for $10.00 (price includes shipment). A 60-page soft-cover book entitled *Chart of the Nuclides* is also available for $10.00 (price includes shipment). The book includes fold-outs of the chart. These items can be obtained from:

General Electric Company
Production Resources
1080 North Seventh Street
San Jose, California 95112

RADIOACTIVITY REVIEW

2.27 Introduction

Before we can understand *radioactivity*, we must first learn something about ourselves and the world around us. All matter, even our own bodies, is composed of *atoms*. There are more than you can possibly imagine. The ink dot at the end of this sentence, for instance, has more than a thousand billion atoms.

2.28 The Atom Defined

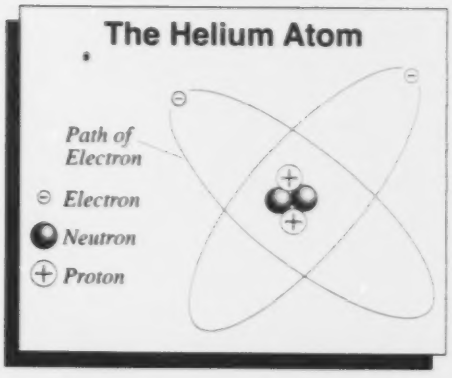
What are atoms?

The atom is the smallest part of an element that has all the chemical properties of that element. The properties of the oxygen and carbon atoms, for example, determine the fact that when wood or coal burns in air, the principal end product is a combination of one carbon atom with two oxygen atoms called carbon dioxide. Similarly, when two hydrogen atoms combine with one oxygen atom, the result is ordinary water.

2.29 A Microscopic Universe

What are the parts of atoms?

The inside of the atom, however, is mostly empty space, a microscopic "universe" occupied by a relatively small number of negative *electrons* revolving around a central mass called the *nucleus*, millions of times smaller than the atom but accounting for nearly all its weight. The nucleus may be considered to be made up of particles called *protons*, with a positive electrical charge, and particles called *neutrons*, which are neutral and have no electrical charge. Protons and neutrons are thousands of times more massive than electrons, which explains why the nucleus accounts for nearly all the weight of the atom.



2.30 The Chemistry of an Element

What is an atomic number?

The number of protons in the nucleus determines what the element is and, therefore, the chemistry of the element. The hydrogen nucleus is a single proton, the carbon nucleus has six protons, and oxygen has eight protons, etc. The *atomic number* of an atom is equal to the number of protons in the nucleus. Its *atomic weight* is the sum of the proton and neutrons in the nucleus. For instance, carbon has 6 protons and 6 neutrons. Its atomic weight is 12 (6 + 6 =12).

What is atomic weight?

2.31 Isotopes

What is an isotope? A radioisotope?

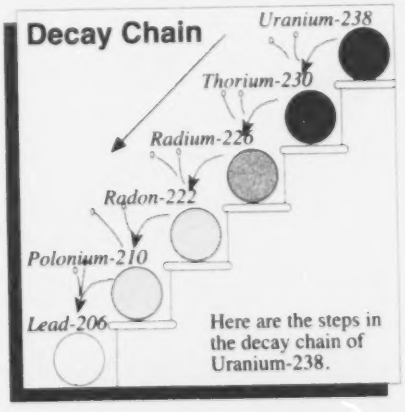
It is possible for atoms having the same chemistry or atomic number (the number of protons) to have different atomic weights because of differing numbers of neutrons. Atoms of the same chemical element having different atomic weights are called *isotopes* of that element. If the isotope is radioactive, it is sometimes referred to as a *radioisotope*.

In the case of atoms that are radioactive, the nucleus spontaneously emits energetic particles or electromagnetic rays that escape the bounds of the atom. This process is *radioactive decay*. Because the emitted particles and rays come from the nucleus, they are referred to as "nuclear" radiations.

2.32 Transformation of Atoms

What are alpha and beta particles?

The nuclei of some radioactive atoms, generally the heavier or larger atoms, expel a part of themselves as a particle composed of two neutrons and two protons (actually a helium nucleus) called an *alpha particle*. By expelling an alpha particle, the nucleus is changed to the nucleus of an element with an atomic number lower by 2 and an atomic weight lower by 4.



Here are the steps in the decay chain of Uranium-238.

In other radioactive nuclei, one of the neutrons emits a negative electron called a *beta particle*. This increases the number of protons in the nucleus by one and converts the atom to another element with an atomic number higher by one.

For example, when the uranium-238 nucleus emits an alpha particle, it becomes the nucleus of a thorium-234 atom. In other words, the uranium atom becomes a thorium atom. It is the same nucleus but the chemistry has changed. When the strontium-90 nucleus emits a beta particle, it becomes the nucleus of yttritium-90. Again, it is the same nucleus, but the chemistry has changed.

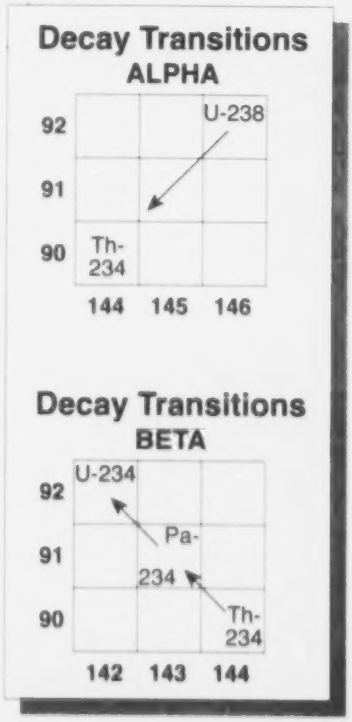
2.33 Radioactive Decay Series

What are the three naturally occurring radioactive decay series?

There are three naturally occurring radioactive decay series: the uranium-238 (U-238), the uranium-235 (U-235), and the thorium-232 (Th-232) series. The very long-lived uranium and thorium isotopes were present in the Earth from the beginning, and the many radioactive atoms resulting from their decay are called their "daughter products."

It is important to understand these naturally occurring decay series and their daughter products and to understand that radioactivity is a fact of life on Earth and not necessarily the product of a nuclear age. It is also important, therefore, to distinguish between the naturally occurring radioactive daughter products like radium-226, radon-222, and polonium-210 and those radioactive "fission products" produced by the fissioning of uranium in a nuclear reactor. The fission products, such as iodine-131, cesium-137, strontium-90, etc., result from the splitting of uranium atoms in a nuclear reaction and are not the products of the radioactive decay of uranium.

Alpha and beta decay: The boxes at right illustrate what happens during decay.



2.34 Alpha Decay

During alpha decay, a uranium-238 nucleus (consisting of 92 protons and 146 neutrons) emits an alpha particle consisting of 2 protons and 2 neutrons. As a result, the nucleus now contains 90 protons and 144 neutrons. This means it is now the nucleus of a thorium atom. This thorium isotope has an atomic weight of 234 (90 + 144 = 234) so it is thorium-234.

2.35 Beta Decay

During beta decay, a neutron in a thorium-234 nucleus (that consists of 90 protons and 144 neutrons) becomes a proton. As a result, the nucleus now consists of 91 protons and 143 neutrons. This means it is an atom of protactinium. This protactinium isotope has an atomic weight of 234 (91 + 143 = 234) so it is protactinium-234.

2.36 Changing Chemistry

What are gamma rays?

Some radioactive materials emit what are called *gamma rays*. Gamma rays are electromagnetic rays that are similar to X-rays but are more energetic. Gamma rays are emitted when a nucleus changes from a higher to a lower energy state, and often accompanies alpha or beta decay. For example, cesium-137, a beta emitter, and radium-236, an alpha emitter, also emit very strong gamma rays.

2.37 Detecting Radioactive Decay

In their study of radioactive materials, scientists use a variety of extremely sensitive instruments. For example, a geiger counter uses high voltages to detect small amounts of radiation, even down to a single ionizing particle. Geiger counters are used to measure radioactivity in natural sources such as rocks and soils, as well as in man-made sources, including spent nuclear fuel.

This and other instruments are helpful in cleaning up research and work facilities where radioactive materials have been present. People at these work locations often wear badges that contain a small bit of photographic film. These film badges record the amount of ionizing radiation to which a worker has been exposed.

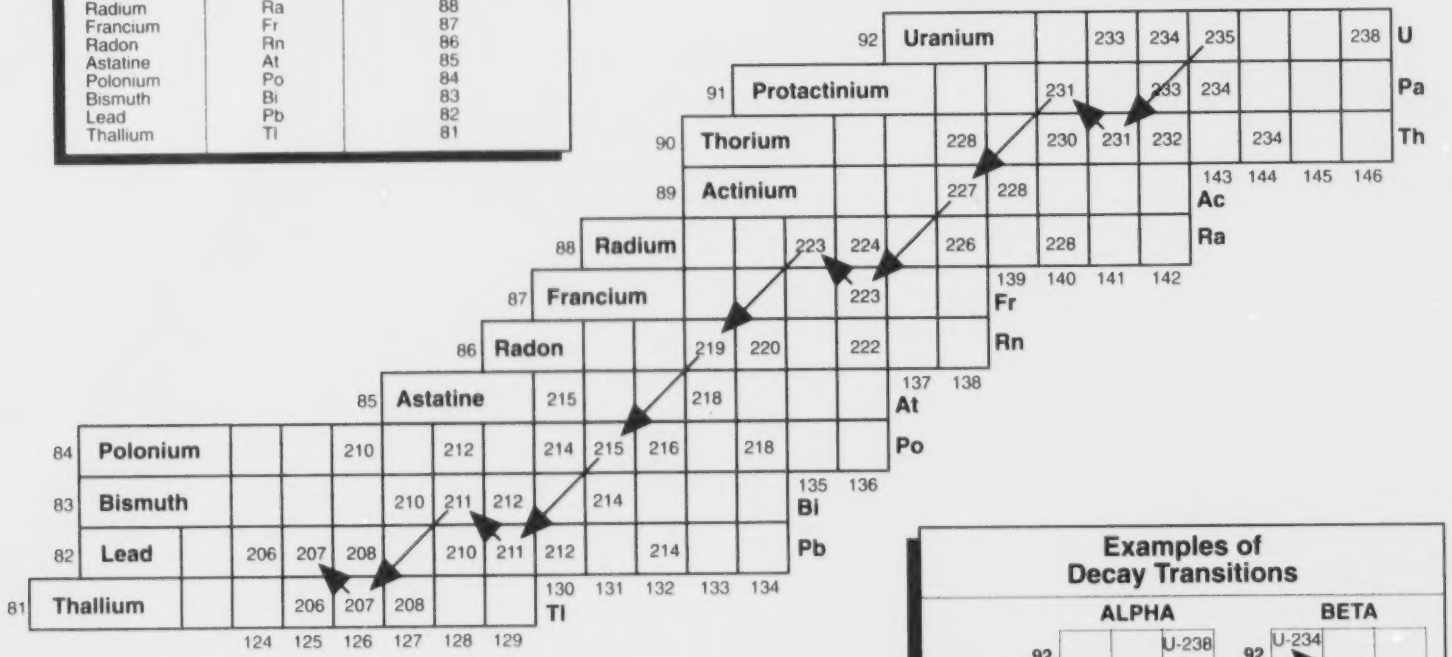
ATOMIC TRANSITIONS IN THE NATURAL RADIOACTIVE DECAY SERIES

Thorium-232			Uranium-235			Uranium-238		
Number of Protons in Nucleus (Atomic Number)	Isotope	Decay	Number of Protons in Nucleus (Atomic Number)	Isotope	Decay	Number of Protons in Nucleus (Atomic Number)	Isotope	Decay
90	Th-232	Alpha	92	U-235	Alpha	92	U-238	Alpha
88	Ra-228	Beta	90	Th-231	Beta	90	Th-234	Beta
89	Ac-228	Beta	91	Pa-231	Alpha	91	Pa-234	Beta
90	Th-228	Alpha	89	Ac-227	Alpha	92	U-234	Alpha
88	Ra-224	Alpha	87	Fr-223	Beta	90	Th-230	Alpha
86	Rn-220	Alpha	88	Ra-223	Alpha	88	Ra-226	Alpha
84	Po-216	Alpha	86	Rn-219	Alpha	86	Rn-222	Alpha
82	Pb-212	Beta	84	Po-215	Alpha	84	Po-218	Alpha
83	Bi-212	33.7% Alpha	82	Pb-211	Beta	82	Pb-214	Beta
		66.3% Beta	83	Bi-211	Alpha	83	Bi-214	Beta
84	Po-212	Alpha	81	Tl-207	Beta	84	Po-214	Alpha
81	Tl-208	Beta	82	Pb-207	Stable	82	Pb-210	Beta
82	Pb-208	Stable				83	Bi-210	Beta
						84	Po-210	Alpha
						82	Pb-206	Stable

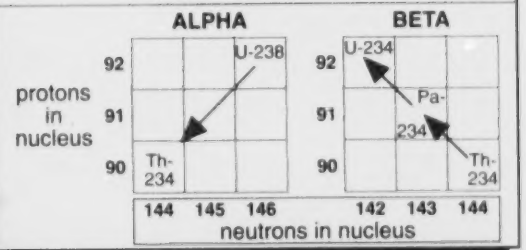
CHART OF THE ISOTOPES IN THE U-238, U-235, and Th-232 DECAY SERIES ANSWERS

Element	Symbol	Number of Protons in Nucleus (Atomic Number)
Uranium	U	92
Protactinium	Pa	91
Thorium	Th	90
Actinium	Ac	89
Radium	Ra	88
Francium	Fr	87
Radon	Rn	86
Astatine	At	85
Polonium	Po	84
Bismuth	Bi	83
Lead	Pb	82
Thallium	Tl	81

Uranium-235 Series



Examples of Decay Transitions



SOME IMPORTANT TRANSITIONS IN SPENT FUEL

Purpose:

This lesson will facilitate the student understanding of the fact that though approximately 90 percent of spent fuel's radioactivity will be lost within 10 years, it contains material that will continue to emit radiation for thousands of years. An understanding of this aspect of the decay process is necessary in order for students to appreciate the need for extreme caution in the handling and storage of spent fuel.

Concept:

Radioactive materials emit radiation in the form of alpha or beta particles during the process known as radioactive decay.

Duration of Lesson:

One 50-minute class period

Objectives:

As a result of completion of the lesson and activity dealing with important atomic transitions in spent fuel, the learner will be able to:

1. discuss and explain that during the process known as radioactive decay, radioactive materials emit radiation in the form of alpha and beta particles; and
2. synthesize why it is necessary that extreme caution be exercised in the handling and storage of spent fuel.

Skills:

Completing charts, discussing, interpreting charts, synthesizing

Vocabulary:

Atomic, noble gas, nuclear reactor, nuclides, transition

Materials:

Reading Lesson

Nuclear Waste: What Is It? Where Is It? - Unit 1, p. SR-9

Activity Sheets

Table of Some Important Atomic Transitions in Spent Fuel, p. 147
Chart of Some Important Isotopes in Spent Fuel, p. 149

Background Notes

Some Decay Transitions in Spent Fuel, p. 71

Suggested Procedure:

1. If you have not already assigned reading of the lesson entitled *Nuclear Waste: What Is It? Where Is It? Section 1.17 Spent Fuel*, do so at this time.
2. Review examples of decay transitions on the bottom of the activity entitled *Some Important Decay Transitions in Spent Fuel*. Instruct students to plot alpha and beta decay transitions, using the table *Some Important Atomic Transitions in Spent Fuel* to assist them.
3. Ask students to explain the significance of what they have just plotted on their charts.

Sample Discussion Questions:

1. Why are these elements that decay considered to be unstable?

   (These elements are called unstable because they are in the process of stabilizing themselves by emitting gamma rays or changing into another element by emitting alpha and beta particles.)

2. What is significant about the fact that unstable elements seek to stabilize themselves?

   (During the process of decay these elements emit radioactivity, in the process becoming less and less radioactive until they ultimately become stable elements such as lead. The significant thing to remember about decay is that different elements stabilize at different rates; some doing so very quickly, others taking thousands of years to stabilize.)

3. Explain the relationship of the above questions to the storage of spent fuel.

   (When spent fuel is removed from the reactor it is stored in a deep, steel-lined, concrete pool of water inside a building at the powerplant. While the spent fuel is stored in the water it cools thermally and becomes less radioactive. During the first 3 months of storage, spent fuel loses approximately 50 percent of its radiation. After a year, it will have lost 80 percent and in 10 years, it will have lost 90 percent. However, spent fuel contains some materials that emit radiation for thousands of years; remaining potentially dangerous for a long time. Because of these different rates of decay and the resultant potential for danger, extreme caution must be exercised in the handling and storage of spent fuel.)

Teacher Evaluation of Learner Performance:

Response in discussion and on the activity sheet will indicate level of comprehension.

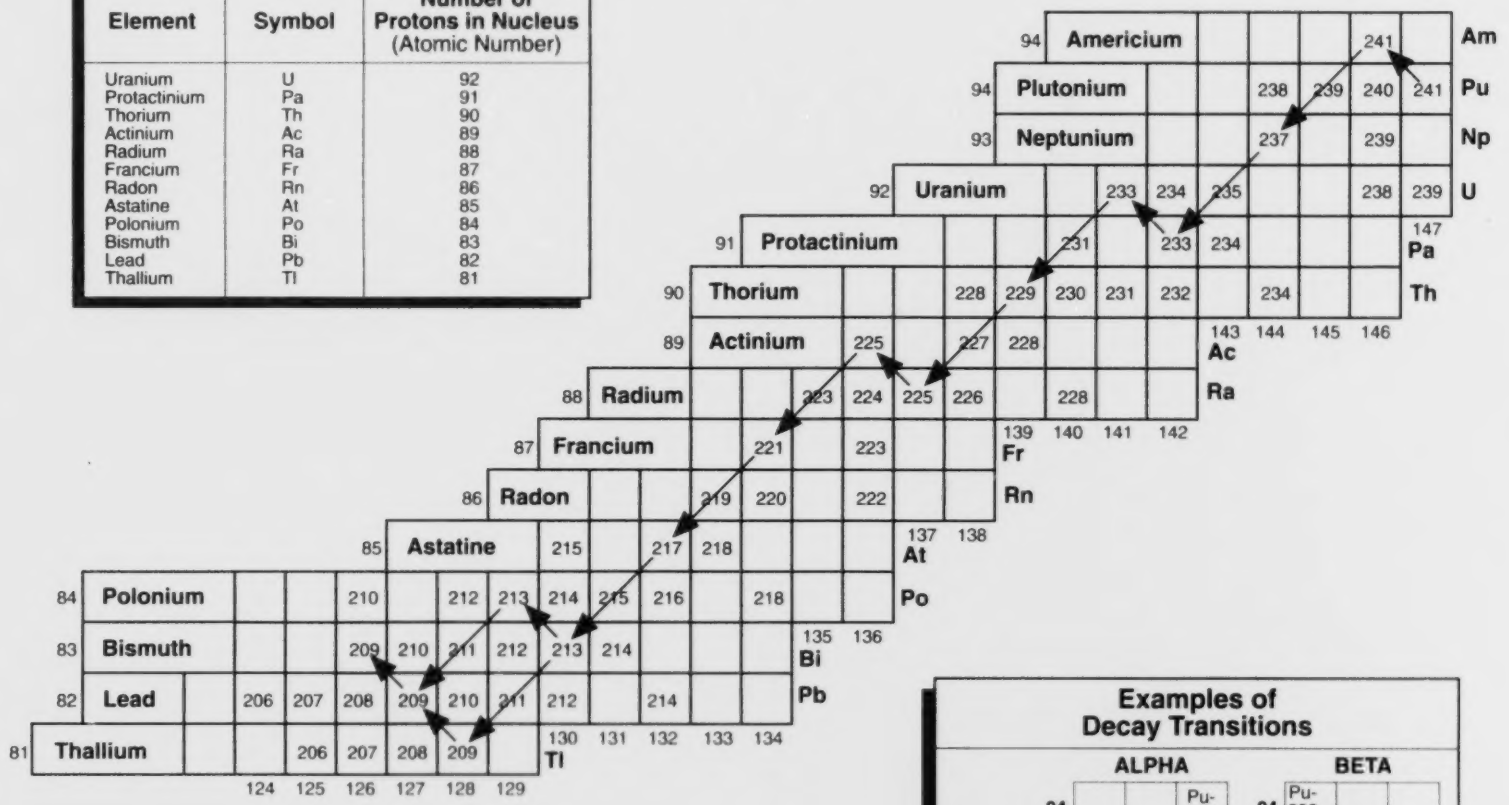
SOME DECAY TRANSITIONS IN SPENT FUEL

			DECAY PRODUCTS		
RADIOISOTOPE	TYPE OF DECAY	HALF-LIFE	ISOTOPIC PRODUCT	TYPE OF DECAY	HALF-LIFE
Fission Products					
Gases					
krypton - 85	Beta	10.72 y	*rubidium - 85*	*Stable*	
xenon - 133	Beta	5.27 d	*cesium - 133*	*Stable*	
Solids					
strontium - 90	Beta	28.1 y	*yttrium - 90*	*Alpha*	*64 h*
molybdenum - 99	Beta	66.7 h	**technetium - 99 m*	*Gamma*	*6 h*
iodine - 131	Beta	8.07 d	*xenon - 131*	*Stable*	
cesium - 137	Beta	30.2 y	*barium - 137*	*Stable*	
cerium - 144	Beta	285 d	*praseodymium - 144*	*Beta*	*17.3 m*
Natural Elements					
uranium - 235	Alpha	710,000,000 y	*thorium - 231*	*Beta*	*25.5 h*
uranium - 238	Alpha	4,500,000,000 y	*thorium - 234*	*Beta*	*24.1 d*
Transuranics					
plutonium - 238	Alpha	86 y	*uranium - 234*	*Alpha*	*247,000 y*
plutonium - 239	Alpha	24,400 y	*uranium - 235*	*Alpha*	*710,000,000 y*
plutonium - 240	Alpha	6,580 y	*uranium - 236*	*Alpha*	*23,900,000 y*
plutonium - 241	Beta	13.2 y	*americium - 241*	*Alpha*	*458 y*
americium - 241	Alpha	458 y	*neptunium - 237*	*Alpha*	*2,140,000 y*
americium - 243	Alpha	7,370 y	***neptunium - 239*	*Beta*	*2.35 d*

* "m" indicates a higher energy level than the natural state (i.e., ground state) of technetium - 99
** decays to plutonium - 239

CHART OF SOME IMPORTANT ISOTOPES IN SPENT FUEL
ANSWERS

Element	Symbol	Number of Protons in Nucleus (Atomic Number)
Uranium	U	92
Protactinium	Pa	91
Thorium	Th	90
Actinium	Ac	89
Radium	Ra	88
Francium	Fr	87
Radon	Rn	86
Astatine	At	85
Polonium	Po	84
Bismuth	Bi	83
Lead	Pb	82
Thallium	Tl	81



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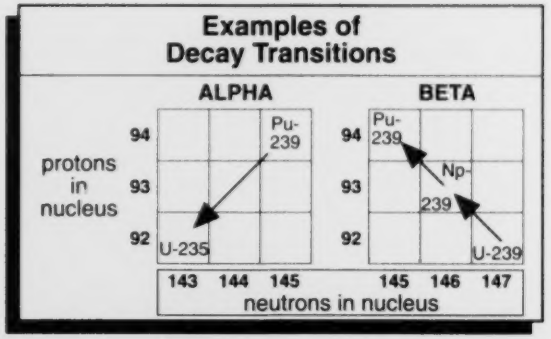

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HAZARDS OF SOME ISOTOPES IN SPENT FUEL COMPARED TO THE HAZARD OF URANIUM ORE

Purpose:

This lesson will enable students to compare the hazard of spent fuel to the hazard of uranium ore, over a range of years. Students will determine at approximately what year the hazard of given isotopes in spent fuel is the same as the hazard of uranium ore. Students will also associate times related to spent fuel decay to events they are familiar with. Logarithmic scale is explained.

Concepts:

1. Spent fuel becomes less hazardous over a period of time covering tens of thousands of years.
2. The period of time over which spent fuel decays is analogous to periods of time in the history of the Earth.
3. Ultimately spent fuel will present no more hazard than naturally occurring uranium ore.
4. Logarithmic scales enable us to represent very long periods of time in a graph.

Duration of lesson:

One 50-minute class period

Objectives:

As a result of participation in this lesson, the learner will be able to:

1. read a graph that uses logarithmic scale;
2. state approximately how long it takes for some specific isotopes in spent fuel to decay to the point that they present the same hazard as uranium ore;
3. state approximately how long it takes for the isotopes in spent fuel considered as a single entity to decay to the point that they present the same hazard as uranium ore; and
4. make comparisons between time of spent fuel storage and time in the past.

Skills:

Drawing conclusions, reading and interpreting a graph

Vocabulary:

Accessible environment, axis, exponent, hazard, isolation, isotope, linear scale, logarithmic scale, primate hominid, relative hazard

Materials:

Activity Sheets

Hazards of Some Isotopes in Spent Fuel Compared to the Hazard of Uranium Ore, p. 153
Graph Entitled Hazards of Some Isotopes in Spent Fuel Compared to the Hazard of Uranium Ore, p. 155

Transparencies

Hazards of Some Isotopes in Spent Fuel Compared to the Hazard of Uranium Ore, p. 151

Background Notes

Hazards of Some Isotopes in Spent Fuel Compared to the Hazard of Uranium Ore, p. 77

The Logarithmic Scale, p. 78

Suggested Procedure:

1. This lesson requires students to read the graph entitled *Hazards of Some Isotopes in Spent Fuel Compared to the Hazard of Uranium Ore*. Students are accustomed to reading graphs that use the linear scale, but this graph uses a logarithmic scale. Introduce logarithmic scale by having students complete Part I of the activity entitled *Hazards of Some Isotopes in Spent Fuel Compared to the Hazard of Uranium Ore*. Part I orients the students to the graph and requires them to identify the information represented by the x axis and the y axis. It may be helpful to do Part I as a class. Ask students why they are comparing these radioisotopes to uranium ore. (Uranium ore is naturally occurring.)
2. When students have completed Part I, they can complete Part II or skip to Part III. Part II will require students to recall what they learned in charting the steps in the decay series (Unit 2 Enrichment) and in charting some of the transitions in spent fuel. This section may be completed on an individual basis, in small groups, or as a class.
3. Part III can be completed on an individual basis, in small groups, or as a class. This section will give some perspective about the long periods of time involved in spent fuel disposal. One point that may be made as a result of this perspective is that while the time involved in spent fuel storage is long in relation to the lifespan of an individual human, the time is not that long in relation to events that geologists study.

   One problem students may have in completing the section is in the reversal of the timeline across the top of the graph which enables the student to see similar periods of time in both the past and future.
4. Advanced groups may also discuss the concept of using dilutions to express relative hazard as explained in the Background Notes for the lesson.

Teacher Evaluation of Learner Performance:

Student participation in class discussion and completion of the activities entitled *The Logarithmic Scale* and *Hazards of Some Isotopes in Spent Fuel Compared to the Hazard of Uranium Ore* will indicate understanding.

Enrichment:

Students might enjoy making a timeline using a linear scale where each year is represented by one/fourth or one/eighth of an inch to show all the years in the logarithmic scale in the graph. However, it will be too tedious to use a ruler to make the timeline and interested students should convert the scale they select to feet before attempting the project. A timeline would reinforce the very long period of time that is involved and would also demonstrate the utility of using logarithmic scale.

HAZARDS OF SOME ISOTOPES IN SPENT FUEL COMPARED TO THE HAZARD OF URANIUM ORE

All drinking water contains trace quantities of naturally occurring radioisotopes. Researchers have determined what concentrations of radioisotopes in water are safe to drink. Hence, the volume of water required to dilute a given amount of a radioactive material to a safe level (i.e., safe to drink) is often used as a measure of the material's hazard; the more water required, the more hazardous the material.

In the graph, the hazards of the radioisotopes in spent fuel are expressed in terms of the volume of water required to dilute them to a safe level compared to the volume of water required to dilute, to a safe level, the uranium ore from which the fuel was prepared. For example, diluting the activity of Cs-137 initially present in the spent fuel requires about 100 times as much water as would be required for the uranium ore.

(Note: The dilutions referred to are hypothetical measurements. The spent fuel is a solid, not a liquid.)

The Logarithmic Scale

If we want to plot something that changes with time and the time period is relatively short, we often use a linear scale. Thus if we were considering 1,000 years, the linear scale might look like this: Each tick mark represents 100 years and each subdivision of the scale would be the same length.

Time (Years)

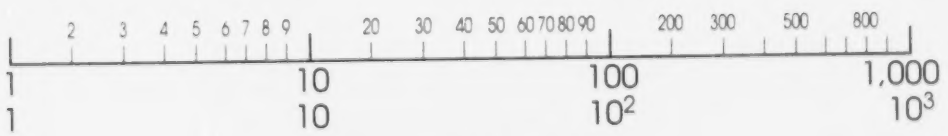
When we consider the many thousands of years it will be necessary to store nuclear waste in a geologic repository, it would not be possible to represent the decay on a linear time scale. Hence, we resort to a convenient device called the logarithmic scale for plotting large numbers.

In the logarithmic scale the only line segments that are equal are those that represent multiples of 10. Thus, 1,000 years on a simple logarithmic scale that showed only the broad divisions would appear thus:

Time (Years)

As you can see, such a scale can plot a great many more years than is possible on a linear scale, but its use would be limited by its lack of detail.

However, if we were to divide each broad segment into nine segments and let the ticks represent the years from 1 to 10, 10 to 100, and 100 to 1,000, the scale would look like this and would be much more useful:



Time (Years)

Note that each broad segment is subdivided in the same way. Each tick within a broad segment represents a multiple of 10 over the corresponding tick in the previous segment. For example, in segment 10^0-10^1 the first mark equals 2. In the segment 10^1-10^2, the first mark equals 20, and in the segment 10^2-10^3, the first mark equals 200.

Note also that the subsections within each broad segment are unequal. The divisions become smaller and represent the years from 1 to 10, or 10 to 100, or 100 to 1,000.

HAZARDS OF SOME ISOTOPES IN SPENT FUEL COMPARED TO THE HAZARD OF URANIUM ORE

Directions: Use the graph entitled *Hazards of Some Isotopes in Spent Fuel Compared to the Hazard of Uranium Ore* to answer the questions below.

Part I

1. Identify the isotopes. (If necessary, refer to the periodic table of the elements.)

^{90}Sr	*Strontium-90*	^{241}Am	*Americium-241*	^{137}Cs	*Cesium-137*
^{238}Pu	*Plutonium-238*	^{240}Pu	*Plutonium-240*	^{239}Pu	*Plutonium-239*
^{237}Np	*Neptunium-237*	^{229}Th	*Thorium-229*	^{210}Pb	*Lead-210*

2. Identify the information on each axis.

X axis (horizontal):

The x axis uses a logarithmic scale (exponential notation) to represent the years of spent fuel storage. How many years are represented by each of the following:

10^{-1}	*0.1*	1	*1*	10	*10*	10^{2}	*100*	10^{3}	*1,000*
10^{4}	*10,000*	10^{5}	*100,000*	10^{6}	*1,000,000*	10^{7}	*10,000,000*		

Y axis (vertical):

Relative hazard is one of many ways to compare the potential hazards of radioactive elements. The y axis measures the "relative hazard" of each isotope compared to the hazard of uranium ore, which is naturally radioactive. Although all the isotopes in spent fuel are not shown, the hazard from all isotopes present in spent fuel, considered as a whole, is shown as "Total."

Like the x axis, the y axis is a logarithmic scale. From the relative hazard list given below, insert the correct term in sentences a-f.

one tenth	one hundredth	ten times
one hundred times	one thousand times	ten thousand times

a. A substance located at 0.01 represents (*one hundredth*) the hazard of uranium ore.

b. A substance located at 0.1 represents (*one tenth*) the hazard of uranium ore.

c. A substance located at 10 represents (*10 times*) the hazard of uranium ore.

d. A substance located at 100 represents (*100 times*) the hazard of uranium ore.

e. A substance located at 1,000 represents (*1,000 times*) the hazard of uranium ore.

f. A substance located at 10,000 represents (*10,000 times*) the hazard of uranium ore.

Part II

1. When spent fuel is first placed in storage, what is the hazard of the isotopes in the spent fuel in comparison to the hazard of uranium ore?

Sr-90 between *100* and *1,000* times (more? less?) hazardous than uranium ore

Cs-137 between *10* and *100* times (more? less?) hazardous than uranium ore

Pu-238 between *10* and *100* times (more? less?) hazardous than uranium ore

Am-241 between *1* and *10* times (more? less?) hazardous than uranium ore

Pu-240 between *1* and *10* times (more? less?) hazardous than uranium ore

Pu-239 between *1* and *10* times (more? less?) hazardous than uranium ore

Np-237 between *1/10* and *1* times (more? less?) hazardous than uranium ore

2. Between what years does each of the following isotopes reach the level of hazard of uranium ore? (The first answer is done as an example.)

Element	Storage Time (Exponential Notation)	Storage Time (Years)
Sr-90	*Between 10^2 and 10^3 years*	*Between 100 and 1,000*
Am-241	*Between 10^3 and 10^4 years*	*Between 1,000 and 10,000*
Cs-137	*Between 10^2 and 10^3 years*	*Between 100 and 1,000*
Pu-238	*Between 10^2 and 10^3 years*	*Between 100 and 1,000*
Pu-239	*Between 10^4 and 10^5 years*	*Between 10,000 and 100,000*
Pu-240	*Between 10^4 and 10^5 years*	*Between 10,000 and 100,000*
Np-237 (first)	*Between 10^2 and 10^3 years*	*Between 100 and 1,000*
Np-237 (second)	*Between 10^6 and 10^7 years*	*Between 100 and 1,000*

Between what years does the hazard of the spent fuel considered as a whole reach the level of hazard of uranium ore?

Total	*Between 10^6 and 10^7 years*	*Between 1,000,000 and 10,000,000*

3. Does the relative hazard for an isotope decrease over the long term? Explain.

(Yes. Radioactive isotopes undergo radioactive decay. As a result, they become less hazardous over long term.)

4. Does the relative hazard for an isotope always decrease over shorter time periods? Explain your answer.

(Over shorter periods of time, the hazard represented by a given isotope may actually increase rather than decrease. This is because the amount of that isotope present in spent fuel may increase because it is created as a product of decay when another isotope in the spent fuel decays.)

5. When the spent fuel is first placed in storage, the relative hazard of neptunium-237 is (less?) than that of uranium ore. After 10^3 years, the hazard has (increased?). Then at about 10^6 years, it (decreases?) to that of uranium ore and continues to (decrease?). Explain how this is possible.

(The increase is the result of radioactive decay of another isotope. Neptunium-237 is a decay product of plutonioum.)

6. Look at the graphs of relative hazard for Th-229 and Pb-210. Notice that their graphs do not even begin until approximately 10,000 years. Where do you think these isotopes come from? How hazardous are they compared to uranium-238?

(Th-229 and and Pb-210 result from decay of other isotopes present in spent fuel. They present less hazard than U-238.)

7. In the graph, the hazard for uranium ore is shown as a constant for comparative purposes. In reality, the hazard for uranium changes over time. Do you think the hazard for uranium would increase or decrease over time? Why?

(Uranium will undergo radioactive decay because it is a radioisotope. As a result of decay, it will become less hazardous.)

8. The canister in which spent fuel will be stored is being designed to provide isolation for a minimum of 300 years. The repository itself must provide isolation of spent fuel from the accessible environment for 10,000 years. Using the information in the graph, explain why 300 years and 10,000 years are reasonable periods of time.

(After about 300 years, isotopes with most intense levels of radioactivity will have decayed so that they present about the same relative hazard as uranium ore. By 10,000 years, isotopes in spent fuel will present about the same hazard as naturally occuring uranium ore that is part of our natural environment.)

Part III

1. The period of time represented on the x axis is very long. To get some perspective of exactly how long, a timeline is shown below that goes back in time. Put the following items on the timeline in the appropriate place by making a tick mark and labeling it. The first item is done as an example. (If necessary, refer back to Part I for the conversions from exponential notations.)

   a. Average lifespan of US citizen—70-72 years

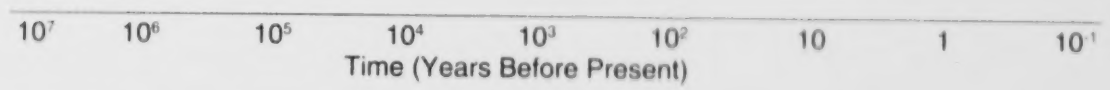
   b. The oldest known living plant (in 1990), a bristle cone pine, which is growing in the Sierra Nevada Mountain, sprouts in the area of the Nevada/California border—4,900 years ago

   c. End of last Ice Age—10,000 years ago

   d. Meteor strikes Arizona and creates Meteor Crater—150,000 years ago

   e. Beginning of last Ice Age—2,500,000 years ago

   f. Earliest primate hominid remains deposited—5,000,000 years ago



2. Despite the length of time represented above, it is not very long in comparison to time spans used to describe the whole history of the Earth. To illustrate this point, several other important dates that geologists have established are given below. What are those dates in years?

   a. Years since the last dinosaurs died: 6.5×10^7 = *65,000,000*

   b. Years since the formation of the Earth: 4.6×10^9 = *4,600,000,000*

   c. How many years elapsed between the formation of the Earth and the end of the dinosaurs? *4,535,000,000*

   d. How many years elapsed between the formation of the Earth and the beginning of the last Ice Age? *4,597,500,000*

   e. How many years elapsed between the end of the dinosaurs and the beginning of the last Ice Age? *64,990,000*

Across the top of the graph entitled "Relative Hazards of Some Isotopes in Spent Fuel Compared to the Hazard of Uranium Ore" are tick marks. Label them to match the timeline for time before the present. Then add points along the top to represent the correct location for items a through f in question 1. This will help you to understand the length of time for storage of spent fuel that is represented by the graph.

Then answer the questions on the next page.

3. Suppose you live in St. Louis and have a time machine and decide to check the figures on this graph. You travel back in time 10^4 years ago. Would you need to take a coat? Why or why not?

(You would need a coat because the last Ice Age would just be ending.)

4. Then you travel into the future. After 5,100 years of travel, a little longer than the length of time the bristle cone pine has lived, you stop to think about the spent fuel in storage.

a. What is the relative hazard of strontium-90 when you check it compared to what its hazard was in the present?
(The relative hazard of strontium-90 will have decreased to the same level as uranium ore before 1,000 years have passed. By 5,100 it will present much less hazard than uranium ore.)

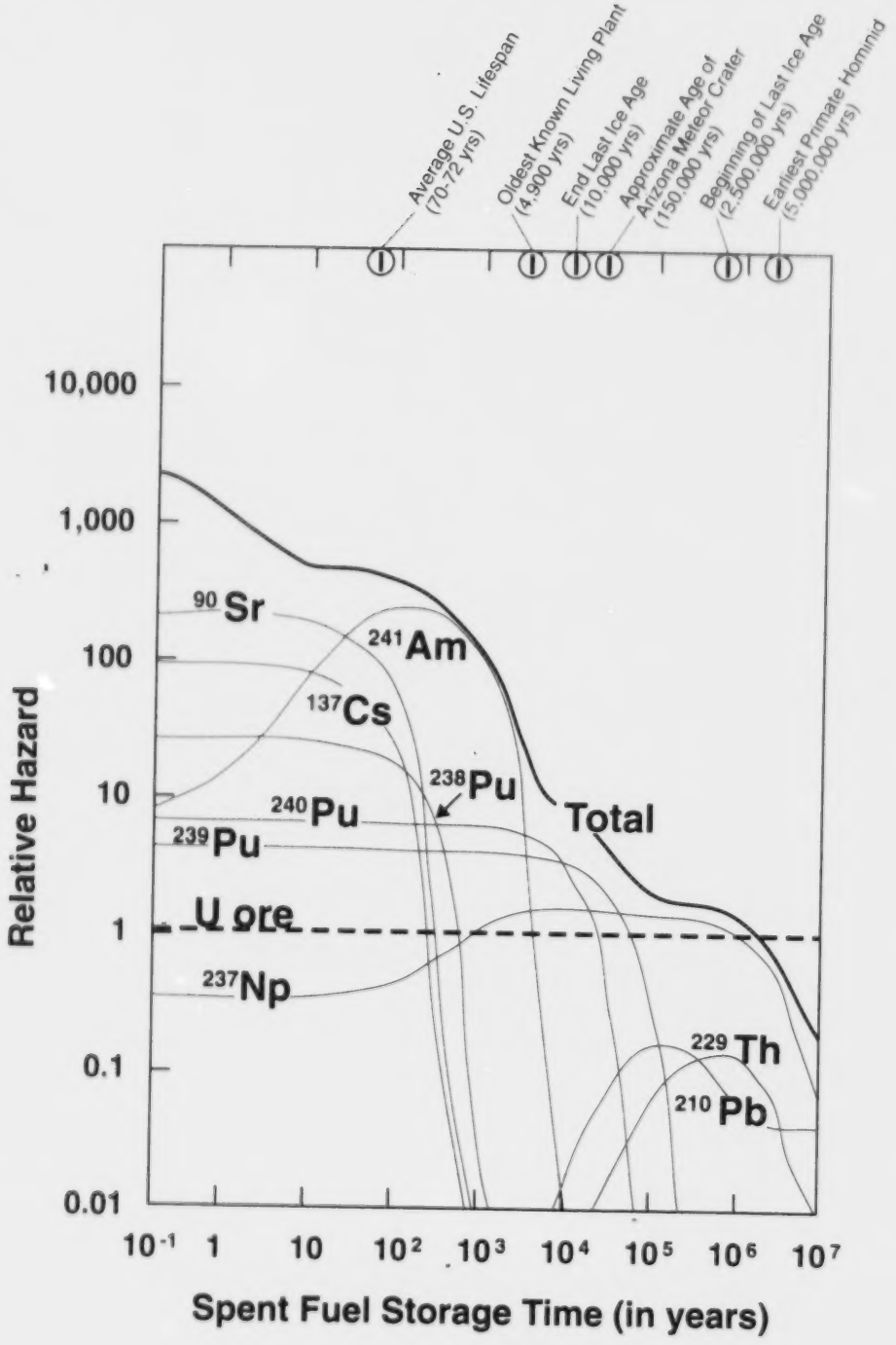
b. What is the relative hazard of Americium-241 in comparison to the hazard of uranium ore? Has the relative hazard changed at all during the 5,100 years? Why or why not?
(Americium-241 will have increased in hazard. There will be more of this isotope present because it is a decay product.)

c. At 5,100 years, what isotopes are still more hazardous than the standard for uranium ore? (Use abbreviations.)
(Am-241, Np-237, Pu-239, Pu-240 will all present more hazard than uranium ore at 5,100 years.)

d. How does the hazard of all the isotopes considered as a whole (i.e., Total) compare to the hazard of uranium ore?
(The total hazard is greater than that presented by uranium ore at 5,100 years.)

e. Why are the decay rates shown important in planning for disposal of spent fuel?
(The hazard of radioactive materials decreases over time. The decay rates tell how long the materials will remain hazardous in comparison to naturally occurring uranium ore. This permits planning for disposal.)

HAZARDS OF SOME ISOTOPES IN SPENT FUEL COMPARED TO THE HAZARD OF URANIUM ORE



Glossary

absorbed dose — The amount of radiation energy absorbed, especially by human tissue; measured in rads.

acceptable level of risk — A level of risk associated with a particular activity at which dangers are acceptable to the evaluator.

accessible environment — The area surrounding a nuclear waste disposal site.

acute exposure — Large exposure received over a short period of time.

alpha particle — A positively charged particle emitted in the radioactive decay of certain radioactive atoms. An alpha particle is identical to the nucleus of the helium atom.

atom — The smallest part of a chemical element that has all the chemical properties of that element.

atomic — Of or relating to an atom.

atomic number — The number of protons (or number of positive charges) in the nucleus of an atom. The number of protons determines what an atom is chemically, and, hence, identifies it as belonging to a certain chemical element.

atomic weight — The sum of the protons and neutrons in the nucleus of an atom.

axis — (geography) A straight line about which a body is symmetrical. (graphing) A reference line which distances are measured in a graph.

background radiation — The natural radioactivity in the environment. Background radiation consists of cosmic radiation from outer space, radiation from the radioactive elements in rocks and soil, and radiation from radon and its decay products in the air we breathe.

beta particle — A negatively charged particle that is emitted by certain radioactive atoms. A beta particle is identical to the electron.

cancer — An abnormal mass of new tissue growing uncontrollably on or in the body; a disease in which such growths form.

catastrophic — Disastrous.

cosmic radiation — Energetic particles and rays from space that strike the Earth at nearly the speed of light.

decay product — The isotope produced by the decay of a radioactive isotope.

DNA (deoxyribonucleic acid) — The part of living cells that determines hereditary characteristics. It consists of two long chains of alternating phosphate and deoxyribose units twisted into a double helix and joined at the axis of the helix by hydrogen bonds between complimentary base pairs (adenine and thymine or cytosine and guanine). The linear sequences of base pairs make up the "genes" that determine hereditary characteristics.

electromagnetic spectrum — The complete range of frequencies of electromagnetic waves from the lowest to the highest, including radio infrared, visible light, ultraviolet, X-ray, gamma ray, and cosmic ray waves.

electron — A subatomic particle with a negative charge. The electron circles the nucleus of an atom.

emit — To send out.

erg — An extremely small amount of energy. Example: to raise a pound weight one foot would require about 13.6 million ergs.

exponent — A symbol above and to the right of a mathematical expression to indicate the operation of raising to a power.

factor — Any of the numbers or symbols in mathematics that yield a product when multiplied together. Any related or relevant subject considered to reach a conclusion.

fission — The splitting of a fissionable nucleus into two smaller, nearly equal, radioactive nuclei, accompanied by the emission of two or more neutrons and a significant amount of energy. Fission in a nuclear reactor is initiated by the fissionable nucleus absorbing a neutron.

frequency — The number of cycles per second of a wave.

gamma ray — Gamma radiation emitted during the radioactive decay of certain radioactive materials.

genetic effect — Effect that can be transferred from parent to offspring.

global — Of or pertaining to the whole world, worldwide.

gonad — One of the primary sex glands. For example: ovaries, testes.

half-life — The amount of time needed for half of the atoms in a quantity of a radioisotope to decay.

ion — Atom, molecule, or molecular fragment carrying a positive or negative electrical charge.

ionization — The production of ions from neutral atoms or molecules by some process. For example, exposure to ionizing radiation.

ionizing radiation — Radiation that has enough energy to remove electrons from substances that it passes through, forming ions.

isolation — Inhibiting the migration of radioactive material to the extent that the amounts entering the accessible environment will not exceed prescribed limits.

isotope — Atoms of the same element that have equal numbers of protons but differing numbers of neutrons.

kilogram — One thousand grams or 2.2046 pounds.

linear scale — Graph scale in which divisions are equal; straight line.

logarithmic scale — Graph scale in which some divisions represent powers of 10 (100,101,102,103, etc.).

millirem — A unit of radiation exposure equal to one-thousandth of a rem.

molecule — The smallest unit into which a chemical compound containing two or more atoms can be divided and still keep all of its chemical characteristics.

mutation — A permanent, transmittable change in the characteristics of an offspring that makes it different from its parents.

neutron — A subatomic particle that appears in the nucleus of all atoms except hydrogen. Neutrons have no electrical charge.

noble gas — A gaseous chemical element that does not readily enter into chemical combination with other elements.

non-ionizing — Low energy radiation such as radio and television waves.

nuclear fuel cycle — The steps necessary to use uranium to produce electricity. These include mining and milling uranium, converting the uranium to a fuel-form, using the uranium as reactor fuel, and disposing of the waste.

nuclear radiation — Ionizing radiation (alpha, beta, and gamma) originating in the nuclei of radioactive atoms.

nuclear reactor — A device in which a fission chain reaction can be initiated, maintained, and controlled.

nucleus — The central part of an atom that contains the protons and neutrons.

nuclides — General term used for radioactive atoms, referred to as radionuclides.

primate hominid — Early manlike creature.

proton — A subatomic particle in the nucleus of an atom with about the same mass as the neutron but carrying a positive charge.

rad (Radiation Absorbed Dose) — A measurement of the energy deposited in any material by ionizing radiation. One rad is equal to the absorption of 100 ergs of energy in every gram of the material exposed to the radiation.

radiation — Energy that moves through space in the form of particles or electromagnetic waves.

radiation sickness — Sickness that results from high exposure to radiation received in a short time. Common symptoms include: nausea, fatigue, vomiting, loss of teeth and hair, and in more severe cases damage to blood-forming tissue and decrease in red and white blood cells. In most cases, prompt medical treatment gradually restores patient's health.

radioactive decay — The spontaneous giving off of an alpha or beta particle or a gamma ray by a radioisotope.

radioisotope — A naturally occurring or artificially created radioactive isotope of a chemical element.

radiologist — Doctor who uses radiation to diagnose and treat medical problems.

radon — A radioactive noble gas.

rem — A unit of exposure to ionizing radiation in human tissue; an estimate of the health risk that exposure to ionizing radiation could have on human tissue.

somatic effect — Effect of radiation limited to the exposed individual.

spent fuel — Fuel that has been used in a nuclear reactor and then withdrawn. Spent fuel is thermally hot and highly radioactive.

sperm — Male reproductive cell that carries genetic material from the father to the offspring.

terrestrial radiation — The portion of natural radiation (background) that is emitted by naturally occurring radioactive materials in the Earth.

transition — The process of changing from one state or style to another; change from one element to another due to the process of radioactive decay.

transuranic — Having an atomic number greater than 92; elements with atomic numbers higher than the atomic number for uranium (92).

ultraviolet light — Light with wavelength shorter than visible light, but longer than X-rays.

uranium — A naturally occurring radioactive element with the atomic number 92 and an atomic weight of approximately 238.

X-ray — Electromagnetic radiation used in medical diagnosis.

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- Cancer Risk Versus Radiation Exposure
- Radiation Exposure Pathways
- Electromagnetic Spectrum
- Radiation Paths in Tissue
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- Calculating Your Personal Radiation Exposure
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Ionizing Radiation

Unit 2 Second Edition
Teacher Guide

THE CLOUD CHAMBER

Three important forms of ionizing radiation are alpha and beta particles and gamma rays. Alpha particles are identical to the nucleus of a helium atom. They have a double positive charge (two protons) and are relatively large. Beta particles are much smaller. They carry a single negative charge (one electron). Gamma rays have no mass or charge.

Ionizing radiation cannot be detected using our senses. However, a cloud chamber allows you to see the tracks it leaves in a dense gas. When charged particles pass through the chamber, they leave a track much like the vapor trail of a jet plane.

PURPOSE:

What is the purpose of this activity?

_____

_____

_____

HYPOTHESIS:

Directions: Draw a picture of what you expect the radiation tracks to look like. Remember that there are three types of radiation: alpha and beta particles and gamma rays.

MATERIALS:

small transparent container with transparent, tight-fitting lid (such as refrigerator jar or cloud chamber purchased from scientific supply company)

flat black spray paint

blotter paper (one strip about 2" wide and long enough to fit around the inside of the jar)

cotton or silk cloth

ethyl alcohol

source (uranium ore, numeral from a luminous dial, purchased source, etc.)

masking tape

"dry ice"

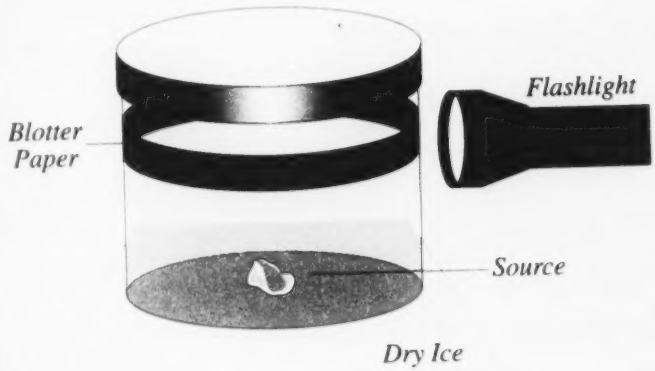
tongs or gloves for handling dry ice

flashlight

CAUTION: DO NOT HANDLE DRY ICE WITH YOUR BARE HANDS. USE TONGS OR GLOVES.

PROCEDURE:

1. Paint the bottom of the jar with the black paint. Allow the paint to dry.
2. Attach the blotter paper to the inside of the jar near the top. You may need to tape it.
3. Pour a very thin layer of ethyl alcohol on the bottom of the jar.
4. Soak the blotting paper ring with alcohol.
5. Place the radiation source on the bottom of the jar and put the lid on tightly. Tape around the lid.



6. Place the jar on top of the dry ice.
7. Allow the jar to super cool for 5 minutes.
8. Darken the room and shine the flashlight through the side of the jar. Through the top, you should see white lines or "tracks" inside the jar close to the bottom.
9. You may be able to find three kinds of tracks:
   a. Most of the tracks will be about 1.3 centimeters (0.5 inch) long and quite sharp. These are made by alpha radiation.
   b. Sometimes you will see longer, thinner tracks. These are made by beta radiation.
   c. Occasionally, you may see some twisting, circling tracks that are so faint that they are difficult to see. These are caused by gamma radiation.

OBSERVATIONS:

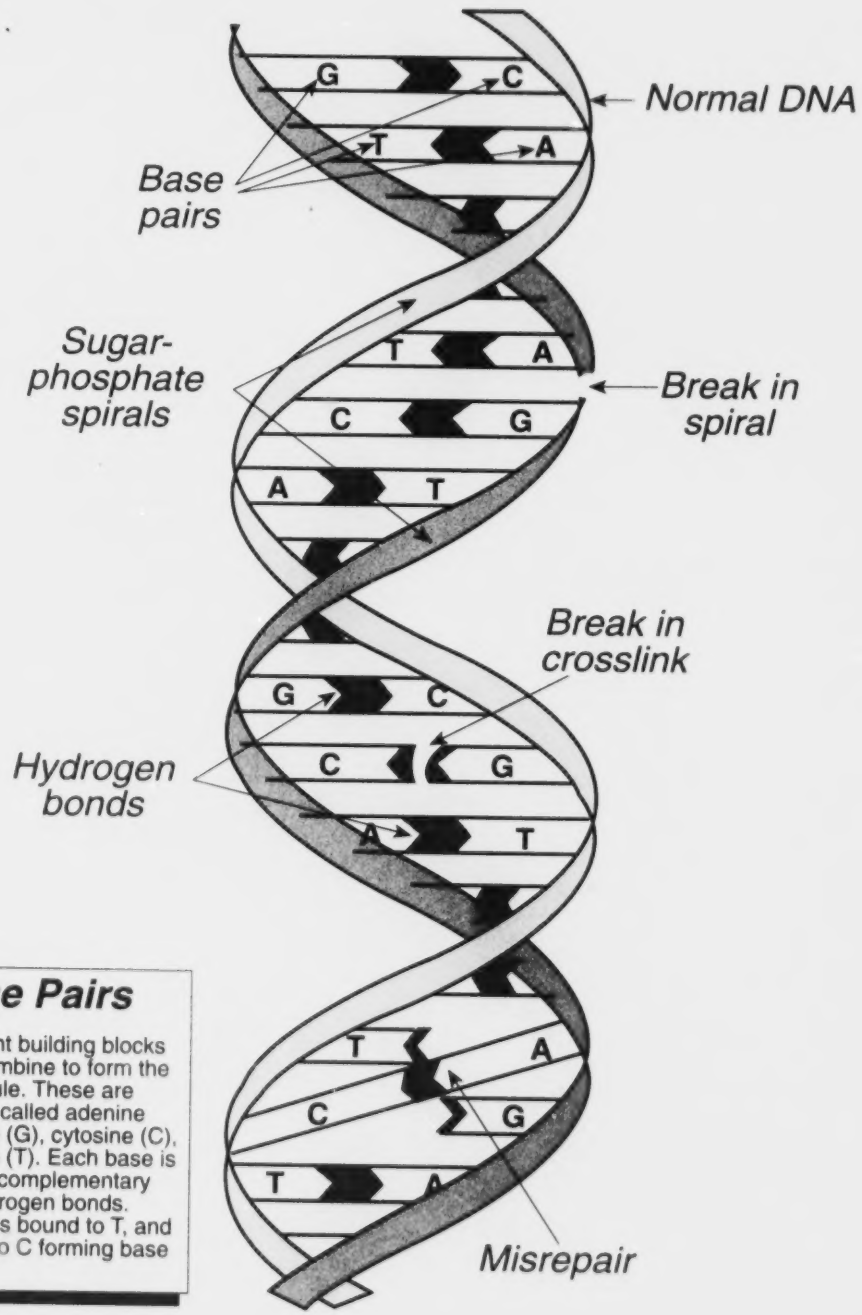
Directions: Draw and label pictures of what you see in the cloud chamber.

CONCLUSION:

1. Were you able to observe radiation directly or indirectly in the cloud chamber?

2. Write a concluding statement explaining how we know radiation exists.

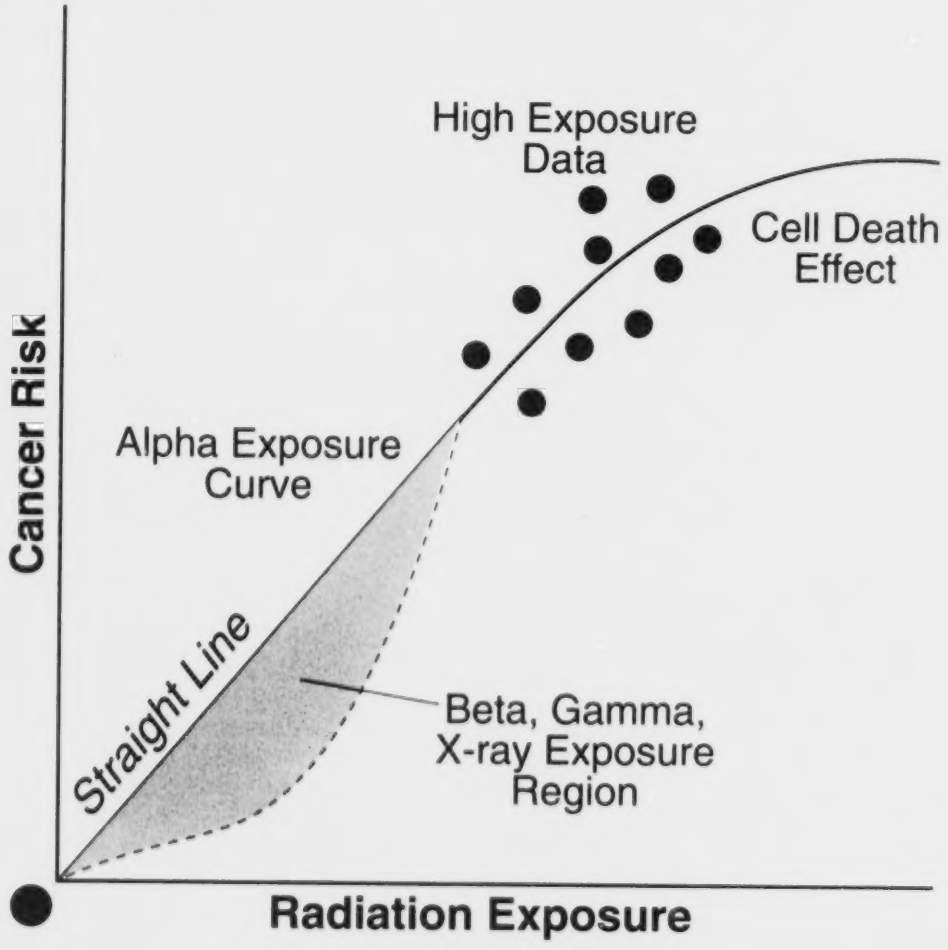
DNA MOLECULE



Base Pairs

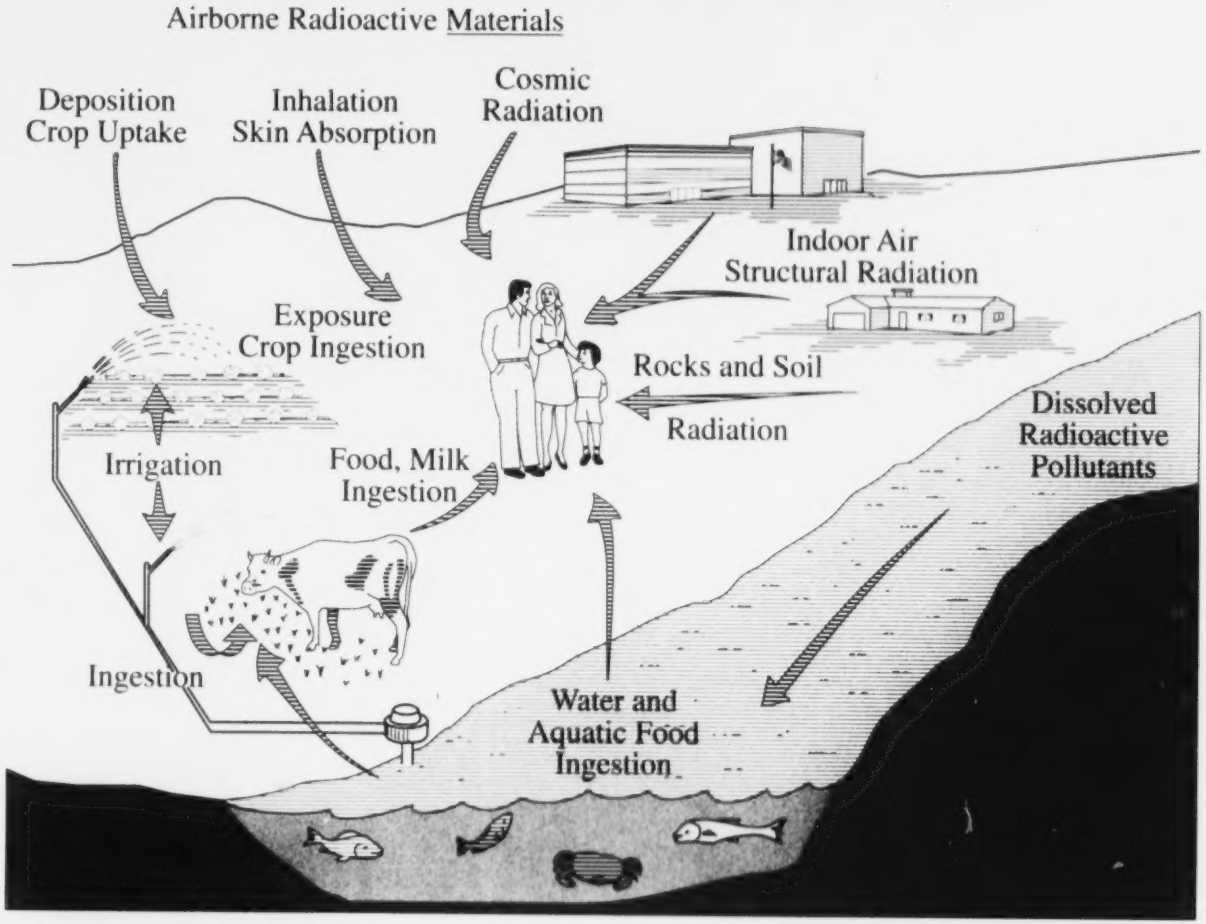
Four different building blocks or bases combine to form the DNA molecule. These are compounds called adenine (A), guanine (G), cytosine (C), and thymine (T). Each base is joined to its complementary base by hydrogen bonds. Normally, A is bound to T, and G is bound to C forming base pairs.

CANCER RISK VERSUS RADIATION EXPOSURE

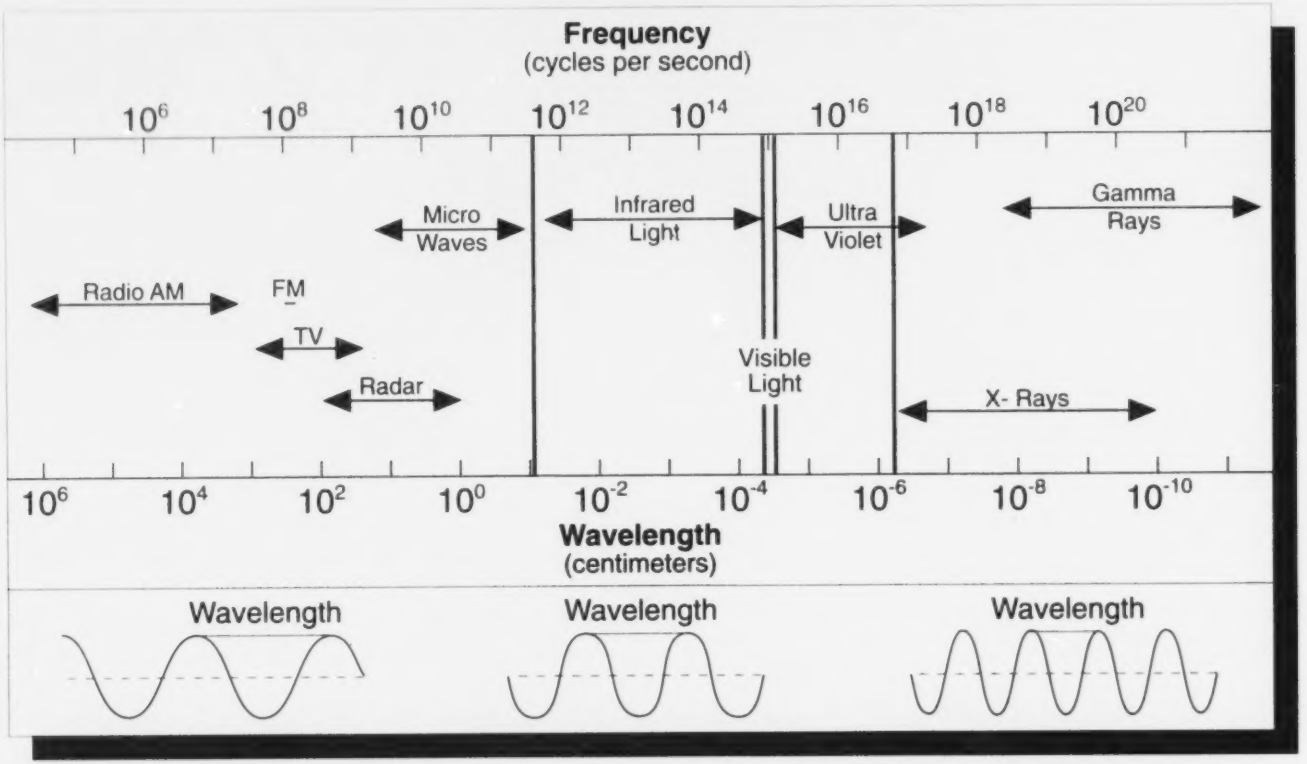


Source: United Nations Scientific Committee on the Effects of Atomic Radiation: Sources, Effects and Risks of Ionizing Radiation, 1988.

Radiation Exposure Pathways

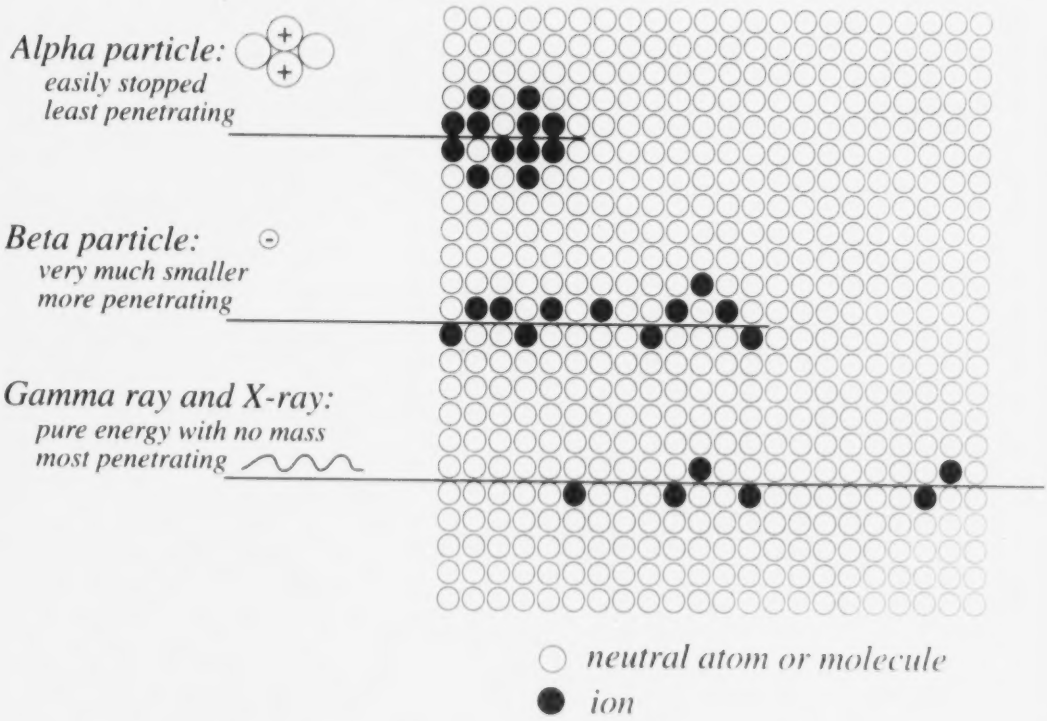


Electromagnetic Spectrum



The gamma rays and X-rays emitted by radioactive materials are waves of pure energy. In common with other electromagnetic waves, they travel at the speed of light and their energies are determined by their frequencies. Alpha and beta particles are not part of the electromagnetic spectrum. They travel at much less than the speed of light and their energies are functions of their velocities and masses.

Radiation Paths in Tissue



Ionizing Radiation Exposure in the United States

Source	Estimated average annual exposure in the U.S. population (millirem)
Natural sources	
Radon	200
Internal radiation	39
Cosmic radiation	31
Terrestrial radiation	28
Manmade:	
X-rays and nuclear medicine	50
Consumer products (including drinking water)	11
Miscellaneous	1
Total	**360**

Source: U.S. Environmental Protection Agency, Radiation: Risks and Realities, *August 1993.*

The percentage contribution to the annual average exposure from various radiation sources is illustrated in the pie chart.

1. Looking at the pie chart, what percentage of the annual average exposure comes from natural sources of radiation (radon, cosmic, terrestrial, internal)?

   _____

2. What is the percentage for man-made sources?

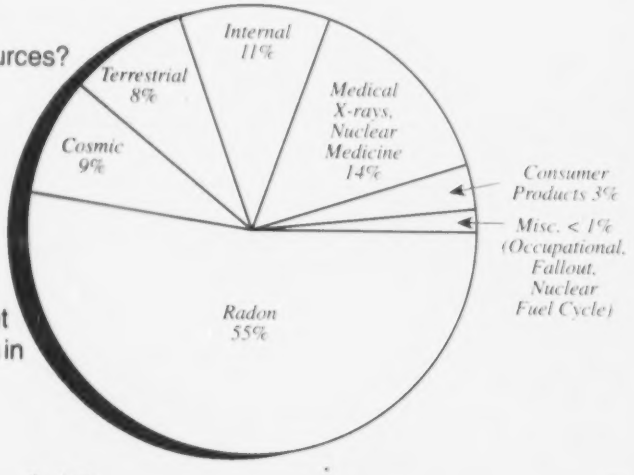
   _____

3. What is our annual internal exposure, in millirem?

   _____

4. What is the average exposure we get annually from radon and its decay products in the air we breathe in millirem?

   _____



CALCULATING YOUR PERSONAL RADIATION EXPOSURE

Directions: Calculate your annual exposure using data in the table of average annual exposures (page 6 of the reading lesson entitled *Ionizing Radiation: Sources and Exposures*) and the information given in the work table below.*

Source of Radiation	Annual Exposure (millirem)

COSMIC RADIATION

Effect of Elevation, in feet (mrem/year):

(Exposures reflect 10% reduction for structural shielding)

0 (sea level)	26	4,000	39
500	27	6,000	52
1,000	28	8,000	74
2,000	31	10,000	107

For your elevation of _____ feet, add _____

GROUND RADIATION (U.S. AVERAGE = 28 MREM/YR)

Average ground radiation for various areas:

Atlantic and Gulf Coastal Plain	16
Colorado Plateau Area	81
Rest of the United States	32

Add the ground radiation exposure for the area in which you live. _____

COSMOGENIC RADIATION: Carbon-14 _____

RADON _____

RADIONUCLIDES IN THE BODY: Air, Water, Food _____

BUILDING MATERIALS

Add 7 mrem/yr 7.0

* In comparing your exposures with those in the main summary table and the pie chart, remember that the table and pie chart contain or reflect numbers obtained by dividing the collective exposures of some segments of the population by the total population of the United States. Such average numbers do not apply to a single, real individual.

MEDICAL DIAGNOSIS

(Add the appropriate exposure for any of the following that you have received.)

X-Rays

chest .....6 mrem	pelvis and hips.....65 mrem	CAT scan ...110 mrem	
extremities...1 mrem	skull, head, neck..20 mrem	PET scan..2000 mrem	

Nuclear Medicine: 430 mrem per treatment (U.S. average) _____

JET PLANE TRAVEL (Add 0.5 mrem per airborne hour) _____

NUCLEAR FUEL CYCLE (Maximum of 0.1 mrem/yr) 0.1

FALLOUT FROM ATMOSPHERIC NUCLEAR WEAPONS TESTING ** 0
(No longer significant)

CONSUMER PRODUCTS

Natural gas heating, cooking: 2 mrem/yr _____

Television viewing: maximum of 1 mrem/yr 1.0

Eyeglasses: 0.4 mrem/yr _____

Gas mantles (camping lanterns): 0.2 mrem/yr _____

Dental ware (crowns, dentures): 0.1 mrem/yr _____

NUCLEAR POWERPLANTS 0.05

TRANSPORTATION OF RADIOACTIVE MATERIALS

Per capita U.S. exposure (1993): less than 0.1 mrem/yr 0.1

RADIOACTIVE WASTE DISPOSAL

Low-level burial waste sites: 1 mrem/yr 1.0

TOTAL _____

What is projected for exposure from a high-level waste repository?

High-level waste repository
Emplacement stage: much less than EPA guideline of 25 mrem/yr
Post-closure: 1 mrem/yr

What is the projected exposure from transporting spent fuel to a repository?

Potential exposure to people living near (100 feet to half a mile) the route of a vehicle traveling at 15 miles per hour (mph) and carrying spent fuel is 0.000001 to 0.001 millirem per shipment.

** Above ground tests of nuclear weapons were conducted prior to 1963. Fallout from these tests is no longer considered significant in figuring exposures to radiation because of dispersion and/or radioactive decay.

PENNIUM-123

The participants will simulate radioactive decay and plot the decay of an isotope of the imaginary element pennium.

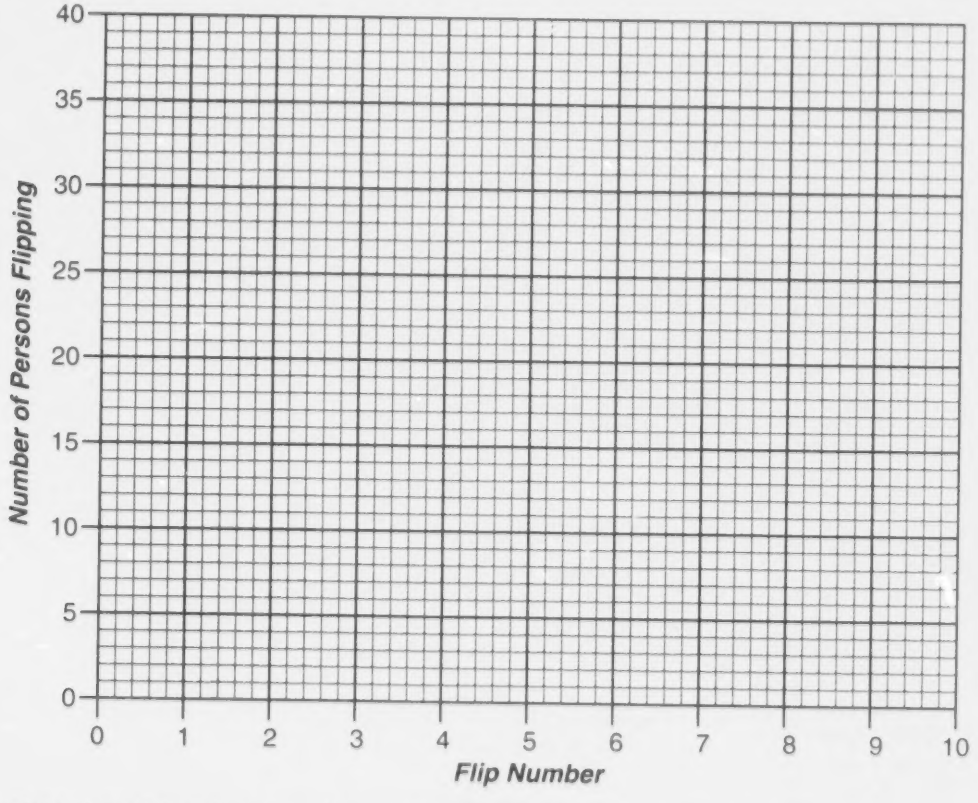
In this activity, everybody has a penny. The discussion leader and participants flip the pennies.

Everyone whose penny matches the leader's flip has "decayed," while those whose penny is different are still "radioactive."

Each time, those who have "decayed" are out.

Count the number out and record the results as indicated on the chart. Then those who are still playing flip again. Continue until everyone is out. Plot the results on the graph below.

Flip Number	Number Decayed	Number Radioactive
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		



Is the number of participants out each turn always one half the number flipped? _____

Why or why not? _____

_____

_____

HALF-LIVES

The half-lives of some significant radioisotopes are listed below. The radioisotopes listed are fission products, naturally occurring radioisotopes, and transuranics. All are present in spent fuel. Fill in the chart below. (The first problem has been done as an example. y=year; d=day; h=hour.)

Radioisotopes	Type of Decay	Half-Life	How long will it take to lose 1/2 of its radioactivity?	How long will it take to lose 3/4 of its radioactivity?	How long will it take to lose 7/8 of its radioactivity?	Specific Activity (curies/gram)
Fission Products						
Gases						
krypton-85	Beta	10.72 y	10.72 y	21.44 y	32.16 y	392
xenon-133	Beta	5.27 d				186,000
Solids						
strontium-90	Beta	28.1 y				141
molybdenum-99	Beta	66.7 h				474,000
iodine-131	Beta	8.07 d				123,500
cesium-137	Beta	30.2 y				86.4
cerium-144	Beta	285 d				3,182
Natural Elements						
uranium-235	Alpha	710,000,000 y				0.00000241
uranium-238	Alpha	4,500,000,000 y				0.000000334
Transuranics						
plutonium-238	Alpha	86 y				17.47
plutonium-239	Alpha	24,400 y				0.0613
plutonium-240	Alpha	6,580 y				0.226
plutonium-241	Beta	13.2 y				112
americium-241	Alpha	458 y				3.24
americium-243	Alpha	7,370 y				0.200

The higher the specific activity of the radioisotope, the more intense the radioactivity and the more particles or rays emitted in a given time period.

1. Which three radioisotopes have the highest specific activity (curies per gram)?

   _____ _____ _____

2. Which three radioisotopes have the lowest specific activity?

   _____ _____ _____

3. What is generally the relationship between specific activity and half-life? Circle the correct word: The more intense the radioactivity, the (longer? shorter?) the half-life.

In your own words, explain the significance of all of the above information as it relates to permanently disposing of radioactive waste.

_____

_____

_____

ENRICHMENT

ATOMS AND ISOTOPES REVIEW

A. Select the word that best fits the definition given.

1. _____ the smallest unit of a chemical element that has all the chemical properties of that element
2. _____ the bundle consisting of protons and neutrons, which is found in the center of an atom
3. _____ atoms of an element containing the same number of protons, but different numbers of neutrons
4. _____ a part of an atom with a positive charge
5. _____ a part of an atom with a negative charge

isotopes	nucleus
atoms	proton
electron	atomic weight

B. Indicate whether each statement is true (T) or false (F) by circling the correct letter. If the statement is false, correct it to make it true.

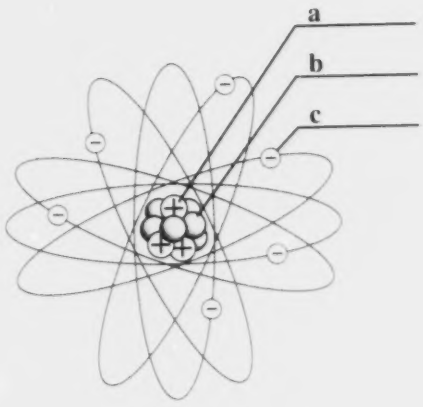
1. Unstable isotopes can change from one form to another by emitting particles and rays. T F
2. An atom is identified by the number of protons in its nucleus. T F
3. Protons and electrons together make up the nucleus of an atom. T F
4. Atoms are so small that humans cannot see them. T F
5. Atoms combine to form molecules. T F

C. Using the periodic table, tell which elements make the molecules of the following substances.

1. H_2SO_4 _____ _____ _____
2. $C_6H_{12}O_6$ _____ _____ _____
3. KOH _____ _____ _____
4. $AgNO_3$ _____ _____ _____
5. $ZnCl_2$ _____ _____

D. Models

1. Label the model of the carbon atom shown to the right. An atom of carbon has 6 protons, 6 neutrons, and 6 electrons. Remember that protons have a positive (+) charge, electrons have a negative (-) charge, and neutrons have no electrical charge.



2. Draw a model of a helium atom. An atom of helium has 2 protons, 2 electrons, and 2 neutrons. Show protons as ⊕, electrons as ⊖, and neutrons as ◯.

THE CHEMICAL ELEMENTS AND ISOTOPES

A chemical element is made up of atoms having the same "atomic number" (i.e., number of protons in the nucleus of each atom) and hence having the same chemical properties. An atom is the smallest unit of a chemical element that has all the chemical properties of that element. All the atoms of a chemical element react with atoms of another chemical element in the same way. Some examples of chemical elements are hydrogen, oxygen, and carbon. Two hydrogen atoms react with one oxygen atom to form a molecule of water (H_2O); a carbon atom reacts with two oxygen atoms to form a molecule of carbon dioxide (CO_2); and so forth.

There are 92 naturally occurring chemical elements. An alphabetical list of the chemical elements and their symbols appear on the following pages.

A chart of the chemical elements called "The Periodic Table" is included. The periodic table is a chart that was originally devised by Dmitri Mendeleev in 1869. The table helps scientists understand the different relationships that elements have to one another. Each square in the periodic table gives information about a separate element.

As noted in the footnotes to the periodic table and earlier, the atomic number is equal to the number of protons in the nucleus of an atom of a chemical element. The number of protons in the nucleus of an atom determines the chemical properties of an atom. Atoms of a chemical element often have different atomic weights because, although the atomic nuclei have the same number of protons, the number of neutrons may differ. Atoms of an element having the same number of protons but different numbers of neutrons are called isotopes of that element.

For example, uranium has several isotopes, which all react in the same way chemically, but their nuclear reactions are different. Uranium-238 does not fission readily. For this reason, uranium-235, which fissions more readily, is used for reactor fuel.

THE CHEMICAL ELEMENTS AND THEIR SYMBOLS

actinium ..... Ac	hafnium ..... Hf	praseodymium .. Pr
aluminum ..... Al	helium ..... He	promethium ..... Pm
americium ..... Am	holmium ..... Ho	protactinium ..... Pa
antimony ..... Sb	hydrogen ..... H	radium ..... Ra
argon ..... Ar	indium ..... In	radon ..... Rn
arsenic ..... As	iodine I	rhenium ..... Re
astatine ..... At	iridium ..... Ir	rhodium ..... Rh
barium ..... Ba	iron ..... Fe	rubidium ..... Rb
berkelium ..... Bk	krypton ..... Kr	ruthenium ..... Ru
beryllium ..... Be	lanthanum ..... La	samarium ..... Sm
bismuth ..... Bi	lawrencium ..... Lr	scandium ..... Sc
boron ..... B	lead ..... Pb	selenium ..... Se
bromine ..... Br	lithium Li	silicon ..... Si
cadmium ..... Cd	lutetium ..... Lu	silver ..... Ag
calcium ..... Ca	magnesium ..... Mg	sodium ..... Na
californium ..... Cf	manganese ..... Mn	strontium ..... Sr
carbon C	mendelevium .... Md	sulfur ..... S
cerium ..... Ce	mercury ..... Hg	tantalum ..... Ta
cesium ..... Cs	molybdenum ..... Mo	technetium ..... Tc
chlorine Cl	neodymium ..... Nd	tellurium ..... Te
chromium ..... Cr	neon ..... Ne	terbium ..... Tb
cobalt ..... Co	neptunium ..... Np	thallium ..... Tl
copper ..... Cu	nickel ..... Ni	thorium ..... Th
curium ..... Cm	niobium ..... Nb	thulium ..... Tm
dysprosium ..... Dy	nitrogen ..... N	tin ..... Sn
einsteinium ..... Es	nobelium ..... No	titanium ..... Ti
erbium ..... Er	osmium ..... Os	tungsten ..... W
europium ..... Eu	oxygen ..... O	uranium ..... U
fermium ..... Fm	palladium ..... Pd	vanadium V
fluorine ..... F	phosphorus ..... P	xenon ..... Xe
francium ..... Fr	platinum ..... Pt	ytterbium ..... Yb
gadolinium ..... Gd	plutonium ..... Pu	yttrium ..... Y
gallium ..... Ga	polonium ..... Po	zinc ..... Zn
germanium ..... Ge	potassium ..... K	zirconium ..... Zr
gold ..... Au		

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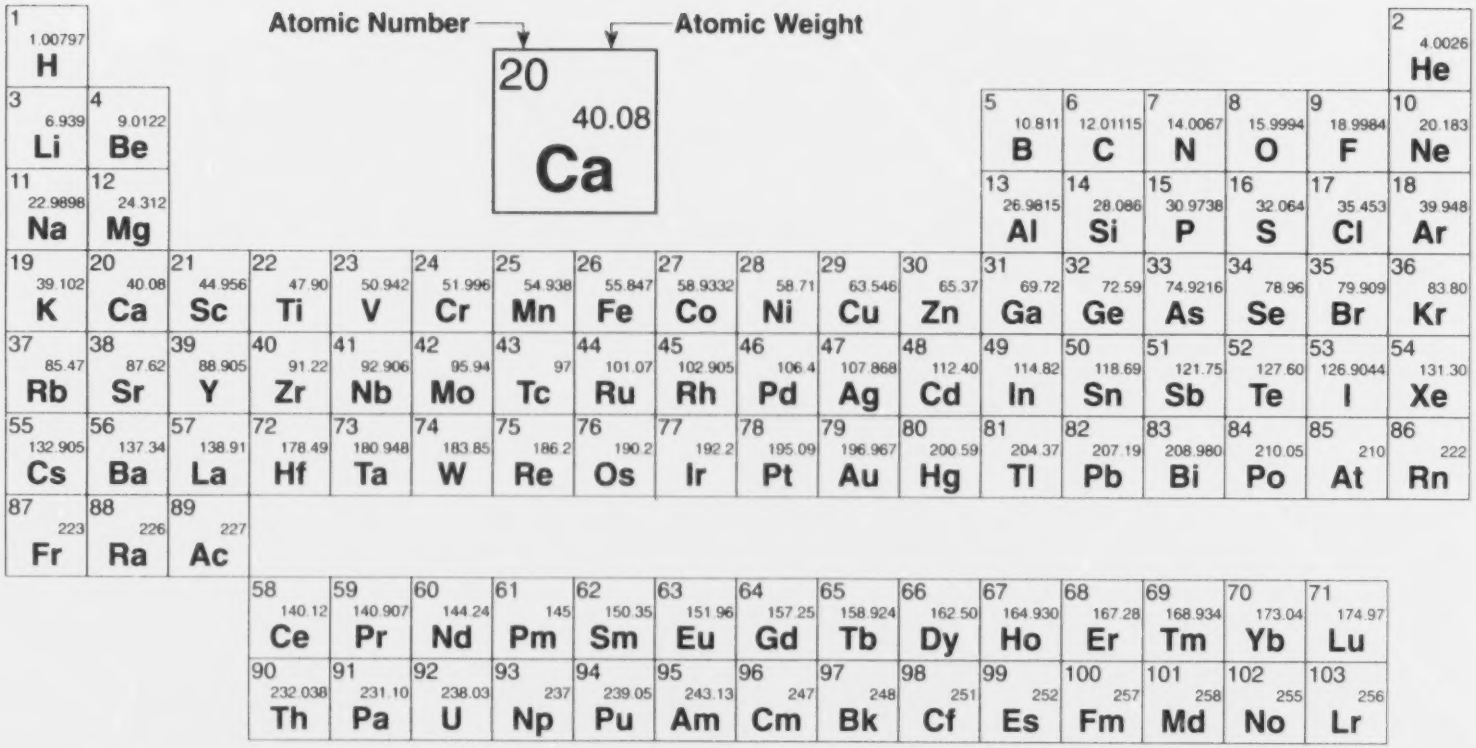
Periodic Table



1 1.00797 H																	2 4.0026 He
3 6.939 Li	4 9.0122 Be											5 10.811 B	6 12.01115 C	7 14.0067 N	8 15.9994 O	9 18.9984 F	10 20.183 Ne
11 22.9898 Na	12 24.312 Mg											13 26.9815 Al	14 28.086 Si	15 30.9738 P	16 32.064 S	17 35.453 Cl	18 39.948 Ar
19 39.102 K	20 40.08 Ca	21 44.956 Sc	22 47.90 Ti	23 50.942 V	24 51.996 Cr	25 54.938 Mn	26 55.847 Fe	27 58.9332 Co	28 58.71 Ni	29 63.546 Cu	30 65.37 Zn	31 69.72 Ga	32 72.59 Ge	33 74.9216 As	34 78.96 Se	35 79.909 Br	36 83.80 Kr
37 85.47 Rb	38 87.62 Sr	39 88.905 Y	40 91.22 Zr	41 92.906 Nb	42 95.94 Mo	43 97 Tc	44 101.07 Ru	45 102.905 Rh	46 106.4 Pd	47 107.868 Ag	48 112.40 Cd	49 114.82 In	50 118.69 Sn	51 121.75 Sb	52 127.60 Te	53 126.9044 I	54 131.30 Xe
55 132.905 Cs	56 137.34 Ba	57 138.91 La	72 178.49 Hf	73 180.948 Ta	74 183.85 W	75 186.2 Re	76 190.2 Os	77 192.2 Ir	78 195.09 Pt	79 196.967 Au	80 200.59 Hg	81 204.37 Tl	82 207.19 Pb	83 208.980 Bi	84 210.05 Po	85 210 At	86 222 Rn
87 223 Fr	88 226 Ra	89 227 Ac															

58 140.12 Ce	59 140.907 Pr	60 144.24 Nd	61 145 Pm	62 150.35 Sm	63 151.96 Eu	64 157.25 Gd	65 158.924 Tb	66 162.50 Dy	67 164.930 Ho	68 167.28 Er	69 168.934 Tm	70 173.04 Yb	71 174.97 Lu
90 232.038 Th	91 231.10 Pa	92 238.03 U	93 237 Np	94 239.05 Pu	95 243.13 Am	96 247 Cm	97 248 Bk	98 251 Cf	99 252 Es	100 257 Fm	101 258 Md	102 255 No	103 256 Lr

1. The capital letter or combination of a capital letter and lower case letter in the center of the box is the symbol for the element. For example, H stands for hydrogen, He for helium.

2. In the upper left corner of each box is the atomic number for the element. This number is equal to the number of protons in the nucleus of the element.

3. In the center of the box is the atomic weight, given in decimals. Atomic weight is the average weight of all isotopes of a particular element. Rounded off to the nearest whole number, the atomic weight is the number of protons and neutrons, of most common isotopes, added together.

CHEMICAL ELEMENT WORKTABLE

DIRECTIONS: Using the list of elements and symbols and the Periodic Table, fill in the chart below. The first example has been completed for you.

Element	Symbol	Atomic Number	Atomic Weight	Atomic Weight (rounded off)	No. of Protons	No. of Neutrons
Gold	Au	79	196.9670	197	79	118
Helium						
Carbon						
Uranium						
Radium						
Plutonium						
Oxygen						
Radon						
Nitrogen						
Calcium						

CHEMICAL ELEMENT WORKTABLE

DIRECTIONS: Name the isotopes by filling in all the blanks below.

Isotopes of a given element are atoms with nuclei that have the same number of protons, but different numbers of neutrons. An isotope is identified by the sum of the number of protons and neutrons in its nucleus. To find the symbol, use the list of elements and symbols. To find the correct number of protons, use the periodic table.

The first example has already been completed.

Element	Symbol	Number Protons	Number Neutrons	Name of Isotope
Uranium	U	92	143	Uranium-235
Uranium			146	
Carbon			8	
Iodine			78	
Strontium			52	
Cesium			82	
Thorium			142	

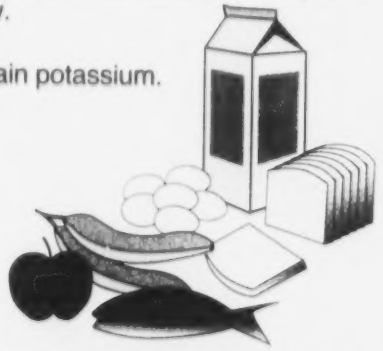
RADIOACTIVITY IN FOOD

Many of the foods that we eat contribute to our internal exposure to radiation. These foods are naturally radioactive. They contain elements like potassium and carbon that are essential for good health and cannot be eliminated from our diets.

Potassium-40

Potassium-40 is a radioactive isotope of naturally occurring potassium. Potassium-40 contributes 18 millirem to our average annual internal radiation exposure.

Directions: Use the chart entitled *Potassium Content and Potassium-40 Activity in Some Selected Foods* to answer the questions that follow.



1. List four foods you have eaten this week that contain potassium.

   _____

   _____

   _____

   _____

2. If the radioactivity of 1 gram of natural potassium is 30 disintegrations per second (d/sec) and a small banana contains about 0.4 grams of natural potassium, what is the number of disintegrations per second of this banana?

3. The activity of the radioactive potassium-40 in your body is about 60 disintegrations per second per kilogram (d/sec/kg) of body weight.

   a. How much do you weigh? (in pounds) _____

   b. If 1 kilogram (kg) = 2.2 lbs., how much do you weigh in kilograms?

c. Given the activity of potassium-40 above, what is the activity of potassium-40 in your body in disintegrations per second (d/sec)?

Carbon-14

The second largest contributor to our annual internal exposure is carbon-14, a naturally occurring radioactive isotope of carbon. It contributes about 1.2 millirem to our average annual internal radiation exposure.

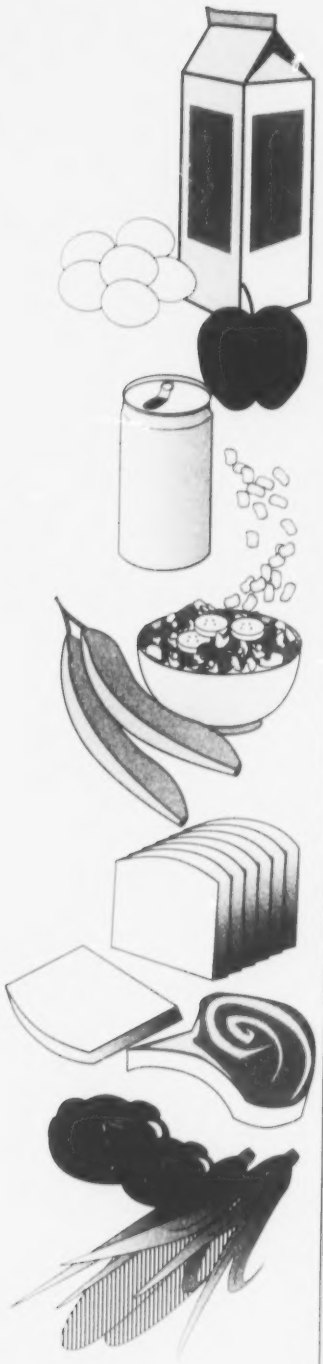
4. Our bodies are about 23 percent carbon by weight. Because it contains some carbon-14, the carbon in your body has an activity of 227 disintegrations per second per kilogram.

   a. Based on your weight in kilograms (from question 3b), how much of your body is carbon? Express your answer in kilograms of carbon.

   b. Given the activity of carbon-14 in the carbon of your body, what is the total activity of the carbon in your body?

Carbon, Potassium, and Your Health

5. Should you try to eliminate all potassium or carbon from your diet in an effort to reduce your annual internal exposure to ionizing radiation? Why or why not?



Potassium Content and Potassium-40 Activity in Some Selected Foods

Food	Portion	Potassium (Milligrams)	Potassium-40 (disintegration per second)
Meat, fish, poultry			
Hamburger	4 ounces	960	29
Salmon, canned	3.5 ounces	350	10.5
Tuna, canned	3.5 ounces	240	7
Chicken, fried	1/4 chicken	240	7
Hot dogs	2 regular	200	6
Bacon	1 strip	17	0.5
Vegetables			
Red kidney beans	1/2 cup	980	29
French fries	3.5 ounces	650	19.5
Potato, baked	1 average	500	15
Broccoli	1 stalk	270	6.6
Tomato	1 small	240	5.7
Corn	1 ear	200	6
Green beans	1/2 cup	100	3
Fruits and fruit juices			
Banana	1 small	370	9
Orange	1 medium	300	7
Orange juice, frozen	1/2 cup	230	7
Apple	1 medium	160	5
Lemonade, frozen	1/2 cup	18	0.5
Milk and milk products			
2%	1 cup	380	11.4
Whole	1 cup	370	11
Yogurt (skim milk)	1 cup	320	9.6
Ice cream	4 ounces	50	1.5
Other beverages			
Hot chocolate	1 packet	190	5.7
Pepsi Cola	12 ounces	13	0.4
Coca Cola	12 ounces	4	0.1
Sprite	12 ounces	0	0
Cereals			
Bran, flakes	1 ounce	140	4.2
Oatmeal	1 cup	130	4
Wheat, shredded	1 ounce	50	1.5
Corn, flakes	1 ounce	14	0.4
Rice, crisped	1 ounce	14	0.4
Bread, crackers, cookies			
Graham crackers (2)	1/2 ounce	50	1.5
Whole wheat, 1 slice	1 ounce	70	2.1
White, 1 slice	1 ounce	30	0.9
Vanilla wafers (5)	1/2 ounce	10	0.3
Miscellaneous			
Sunflower seeds	3.5 ounces	920	27.6
Peanuts	1/2 ounce	110	3.3
Peanut butter	1 tablespoon	100	3
Egg	1 large	65	2

Source: Potassium concentrations from U.S. Dietary Goals, *U.S. Department of Agriculture, 1977 and Natow, A.B. and J. Heslin,* Nutrition for the Prime of Your Life, *New York, McGraw, 1984.*

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Jet Flight Exposure

Because the atmosphere gets less dense as the elevation increases, the cosmic radiation dose rises with increasing elevation. Therefore, passengers on a jet airplane receive an additional dose from cosmic rays during the flight. According to the National Council on Radiation Protection and Measurements, cosmic exposure at 11,887.20 meters (39,000 feet) is 0.5 millirem per hour.

Directions: Figure the radiation exposure from cosmic radiation for the jet flights listed below.

Flight	Round Trip Flight Time	Radiation Exposure
San Francisco to Washington, DC	12 hours	millirem
Atlanta to Chicago	4 hours	millirem
Dallas/Ft. Worth to Chicago	4 hours	millirem
Boston to Los Angeles	10 hours	millirem
Chicago to Honolulu	18 hours	millirem
New York to Las Vegas	10 hours	millirem

Cosmic Radiation

Cosmic rays originate outside the Earth's atmosphere and are composed of highly penetrating radiation of all sorts, both particles and rays. At sea level, the average annual exposure from cosmic rays is 26 millirem. The following table shows the effect of elevation on cosmic ray exposures.

Effect of Elevation, in Feet, on Cosmic Radiation Exposures (MREM/YR)
(exposures reflect 10% reduction for shielding from buildings/structures)

0 (sea level) ...26	4,000 39
500 27	6,000 52
1,000 28	8,000 74
2,000 31	10,000 107

Directions: Using the data in the table above, calculate the cosmic ray exposure where you live and the exposure from cosmic rays for the cities listed below. (Check an atlas for the elevation above sea level of your area.)

Place	Elevation	Exposures from cosmic rays mrem/yr
Your home town		millirem
Atlanta, GA	1,050	millirem
Minneapolis, MN	815	millirem
Salt Lake City, UT	4,400	millirem
Spokane, WA	1,890	millirem

Apollo Flight Exposure

As previously mentioned, U.S. astronauts in Earth orbit or on Moon missions received increased radiation exposure from cosmic rays. The following table shows the estimated exposures by our astronauts on the various Apollo missions. The data are taken from a 1982 report of the United Nations Scientific Committee on the Effect of Atomic Radiation (UNSCEAR) entitled *Ionizing Radiation: Sources and Biological Effects.*

Directions: In the table below, calculate the average rate of exposure in millirem per hour for the various missions.

Estimated Doses Received by Astronauts on the Apollo Missions

Apollo Mission Number	Launch Date	Type of Orbit	Duration of Mission (Hours)	Exposure	
				Total (mrem)	Rate (mrem/hr)
VII	August 1968	Earth orbital	260	120	_____
VIII	December 1968	Circumlunar	147	185	_____
IX	February 1969	Earth orbital	241	210	_____
X	May 1969	Circumlunar	192	470	_____
XI	July 1969	Lunar landing	182	200	_____
XII	November 1969	Lunar landing	236	~200	_____
XIV	January 1971	Lunar landing	286	~500	_____
XV	July 1971	Lunar landing	286	~200	_____

MANMADE RADIATION SOURCES

1. True or False: In the blank before the sentence, write T if the statement is true and F if it is false. If the statement is false, correct it to make it true.

The following questions are based on the graph titled *Some Exposures from Manmade Sources Compared to the Average Natural Radiation Exposure.*

__ a. The exposures from manmade sources shown in the graph are based on the lowest exposures.

__ b. The highest exposure to manmade sources of radiation is from smoking cigarettes.

__ c. There is more exposure from building materials than from storage of low-level waste.

__ d. The only energy use that results in any exposure to radiation is related to nuclear powerplants.

2. List 3 consumer goods that are related to radiation exposure.

_____

_____

_____

3. Write a sentence or two explaining what you think is the source of radioactivity at coal-fired powerplants, construction activities, and fertilizers.

_____

_____

_____

BIOLOGICAL EFFECTS OF IONIZING RADIATION

Refer to the reading entitled *Biological Effects of Ionizing Radiation* to answer the questions below.

1. The principal factors that determine the biological effect of ionizing radiation are _____

   _____

   _____

2. The possibility of injury from ionizing radiation _____ with increasing exposure.

3. Increasing the volume of tissue exposed _____ the severity of radiation injury.

4. Alpha particles deposit all their energy in a _____ path.

5. X-rays and gamma rays deposit their energy over a _____ path.

6. The two main categories of biological effects are _____ effects and _____ effects.

7. Of the two main types of effects in question 6, which applies to the exposed individual and which applies to future generations?

   _____ effects apply to the exposed individual

   _____ effects apply to future generations

8. Background radiation accounts for only _____ to _____ percent of the spontaneous incidence of cancer.

9. The _____ and _____ are particularly sensitive to radiation exposure.

10. For any radiation exposure greater than zero, there is some _____ .

USING HALF-LIVES

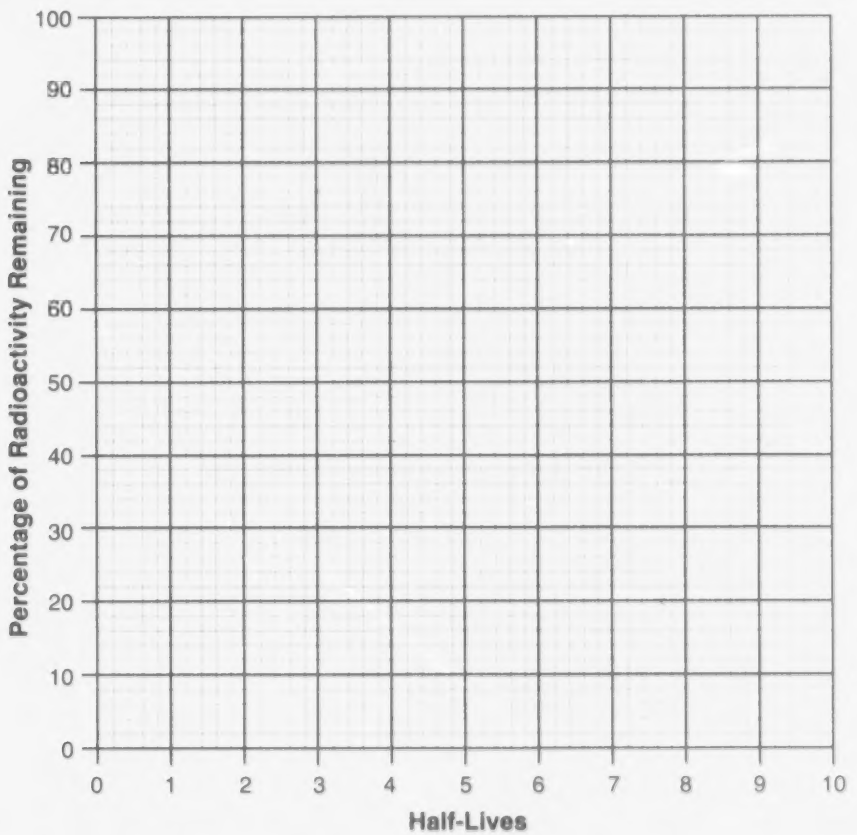
Radioactive materials spontaneously emit ionizing radiation during the process of radioactive decay and become less radioactive over time as a result of this process. The time required for a quantity of a radioactive substance to lose half its radioactivity by radioactive decay is the half-life of that substance. Half-life is a unique characteristic of each radioisotope.

Directions: Answer the following questions by applying the information about half-life given above. Read carefully and think before answering.

1. What percentage of the original radioactivity of a quantity of a radioactive material remains after each half-life?

0	1	2	3	4	5
____	____	____	____	____	____

2. Plot the radioactive decay curve from data in Question 1. On the x-axis plot half-lives and on the y-axis the percentage of radioactivity remaining. Connect each point with straight line segments.



3. Radium has a half-life of 1600 years. Approximately, how long does it take for 1 percent of a sample of radium to decay?

4. Radon has a half-life of 3.8 days. Approximately, how long does it take for 1 percent of a sample of radon to decay? Express your answer in hours.

5. Scientists believe the Earth is 4.6 billion years old.

   a. Approximately what percentage of the uranium-238 originally present is here now if the half-life of uranium-238 is 4.5 billion years?

   b. Calculate a more exact percentage.

6. Calculate approximately what percent of the original thorium-232 is left if it has a half-life of 14 billion years.

7. Uranium-235 has a half-life of 0.7 billion years and also was present when the Earth was formed.

   a. How many U-235 half-lives have occurred since the beginning of the Earth?

   b. Approximately what percent of the original uranium-235 is left?
   (Hint: Make a table of half-lives and calculate the fraction remaining after each half-life)

Half-lives	*1*	*2*	*3*	*4*	*5*	*6*	*7*
Fraction Remaining	___	___	___	___	___	___	___

8. All natural uranium contains both U-235 and U-238. Each decays at a different rate but both are always present in any quantity of natural uranium. We must consider changes in both U-235 and U-238 to calculate the concentration of either at any given time. Keep in mind that natural uranium = U-235 + U-238.

   a. Today, natural uranium contains about 0.7% U-235. How much U-2338 does natural uranium contain today?

   b. The percentages from (a.) are true for any unit of natural uranium. Consider one gram of natural uranium today. What fractional portion of U-235 and of U-238 would comprise that one gram of natural uranium?

   (The choice of one gram as a measure of mass is completely arbitrary. Any mass—one pound, two ounces, etc.—would produce the same answer.)

c. How much U-235 was required 4.6 billion years ago to produce 0.007 grams of U-235 in every gram of natural uranium today? Remember that 1.1% of the total amount of U-235 remains undecayed today. (Question 7b)

d. How much U-238 was required 4.6 billion years ago to produce 0.993 grams of U-238 in every gram of natural uranium today? Remember that 49.45% of the total amount of U-238 remains undecayed today. (Question 5b)

e. Keeping in mind that natural uranium = U-235 + U-238, what percent of U-235 existed in natural uranium 4.6 billion years ago?

9. Based on evidence discovered in 1972, scientists believe that about 2.0 billion years ago, a fission chain reaction occurred spontaneously at Oklo, Gabon, in Africa. Remember that natural uranium = U-235 + U-238 and that U-235 at some concentration was necessary for this reaction to occur. Answer the following to determine the concentration of U-235 in natural uranium 2.0 billion years ago.

   a. How much time had elapsed since the formation of the Earth 4.6 billion years ago when the reaction at Oklo occurred?

   b. At the time of the Oklo reaction, how many half-lives of U-235 and of U-238 had elapsed?

   c. What percentage of the original amount of U-235 and U-238 remained at the time of the nuclear reaction in Oklo, Gabon?

   d. 4.6 billion years ago natural uranium was 24.05% U-235. (Question 8). What percent of natural uranium was U-238?

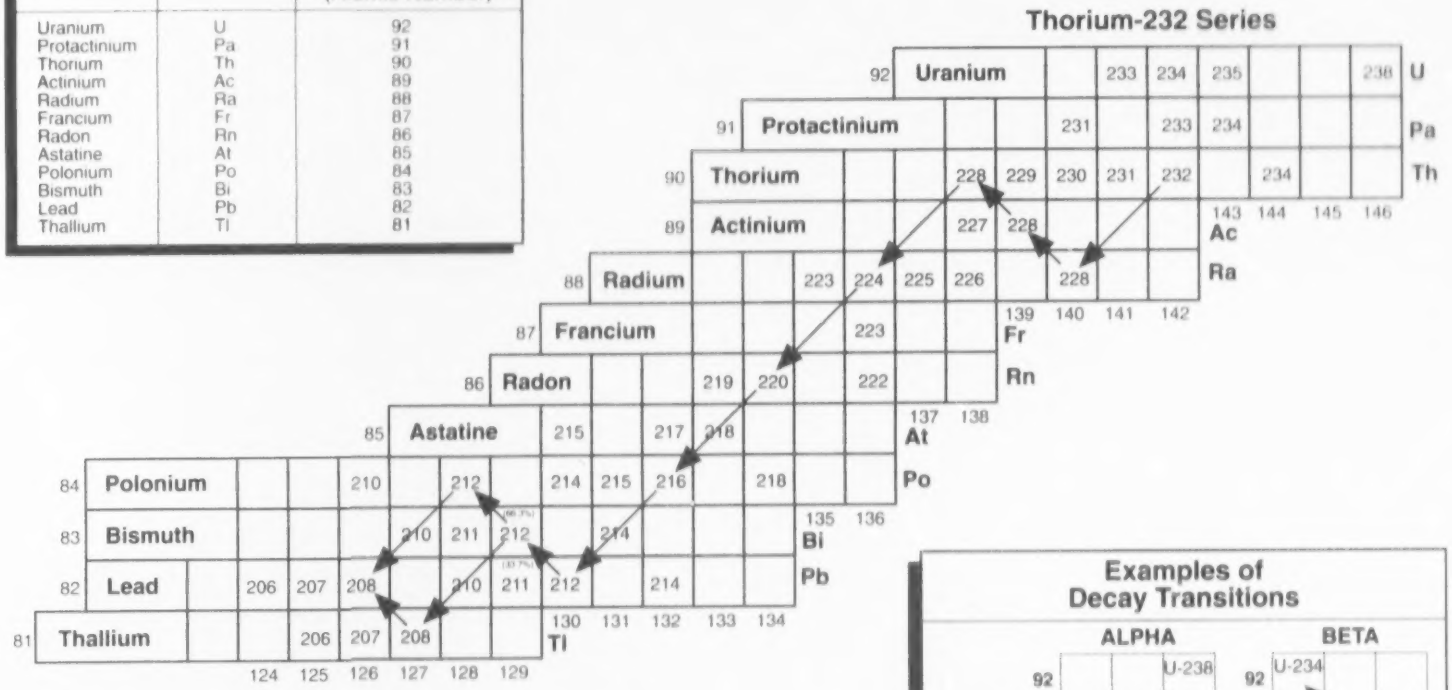
e. Consider one gram of natural uranium 4.6 billion years ago. What fractional portion of U-235 and U-238 would comprise that one gram?

f. If the one gram of natural uranium from (e.) were to decay until the time of the Oklo reaction, how many grams of U-235 and U-238 would remain?

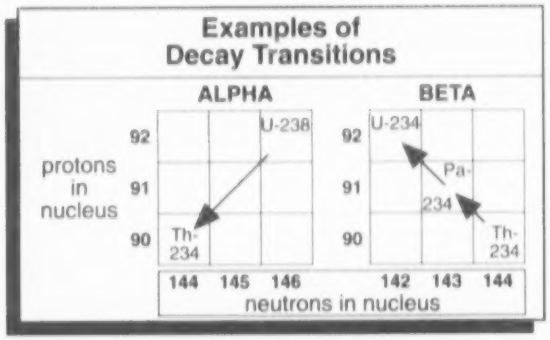
g. Keeping in mind that natural uranium = U-235 + U-238, what percent of U-235 existed in natural uranium at the time of the Oklo reaction?

CHART OF THE ISOTOPES IN THE U-238, U-235, AND Th-232 DECAY SERIES

Element	Symbol	Number of Protons in Nucleus (Atomic Number)
Uranium	U	92
Protactinium	Pa	91
Thorium	Th	90
Actinium	Ac	89
Radium	Ra	88
Francium	Fr	87
Radon	Rn	86
Astatine	At	85
Polonium	Po	84
Bismuth	Bi	83
Lead	Pb	82
Thallium	Tl	81



Adapted from The Chart of the Nuclides, Knolls Atomic Power Laboratory, Schenectady, New York, Operated by General Electric Company for Naval Reactors, the United States Department of Energy



ATOMIC TRANSITIONS IN THE NATURAL RADIOACTIVE DECAY SERIES

Directions:

1. Using the table of atomic transitions, trace the thorium-232 decay series on the chart of the isotopes.
2. Using the information provided in the table of atomic transitions, plot the transitions in the uranium-235 decay series on the chart of the isotopes.
3. Using the plot of the transitions in the uranium-238 series given on the chart of the isotopes, fill in the blanks on the table of atomic transitions.

Thorium-232			Uranium-235			Uranium-238		
Number of Protons in Nucleus (Atomic Number)	Isotope	Decay	Number of Protons in Nucleus (Atomic Number)	Isotope	Decay	Number of Protons in Nucleus (Atomic Number)	Isotope	Decay
90	Th-232	Alpha	92	U-235	Alpha	92	U-238	Alpha
88	Ra-228	Beta	90	Th-231	Beta			
89	Ac-228	Beta	91	Pa-231	Alpha			
90	Th-228	Alpha	89	Ac-227	Alpha			
88	Ra-224	Alpha	87	Fr-223	Beta			
86	Rn-220	Alpha	88	Ra-223	Alpha			
84	Po-216	Alpha	86	Rn-219	Alpha			
82	Pb-212	Beta	84	Po-215	Alpha			
83	Bi-212	33.7% Alpha	82	Pb-211	Beta			
		66.3% Beta	83	Bi-211	Alpha			
84	Po-212	Alpha	81	Tl-207	Beta			
81	Tl-208	Beta	82	Pb-207	Stable			
82	Pb-208	Stable						
						82	Pb-206	Stable

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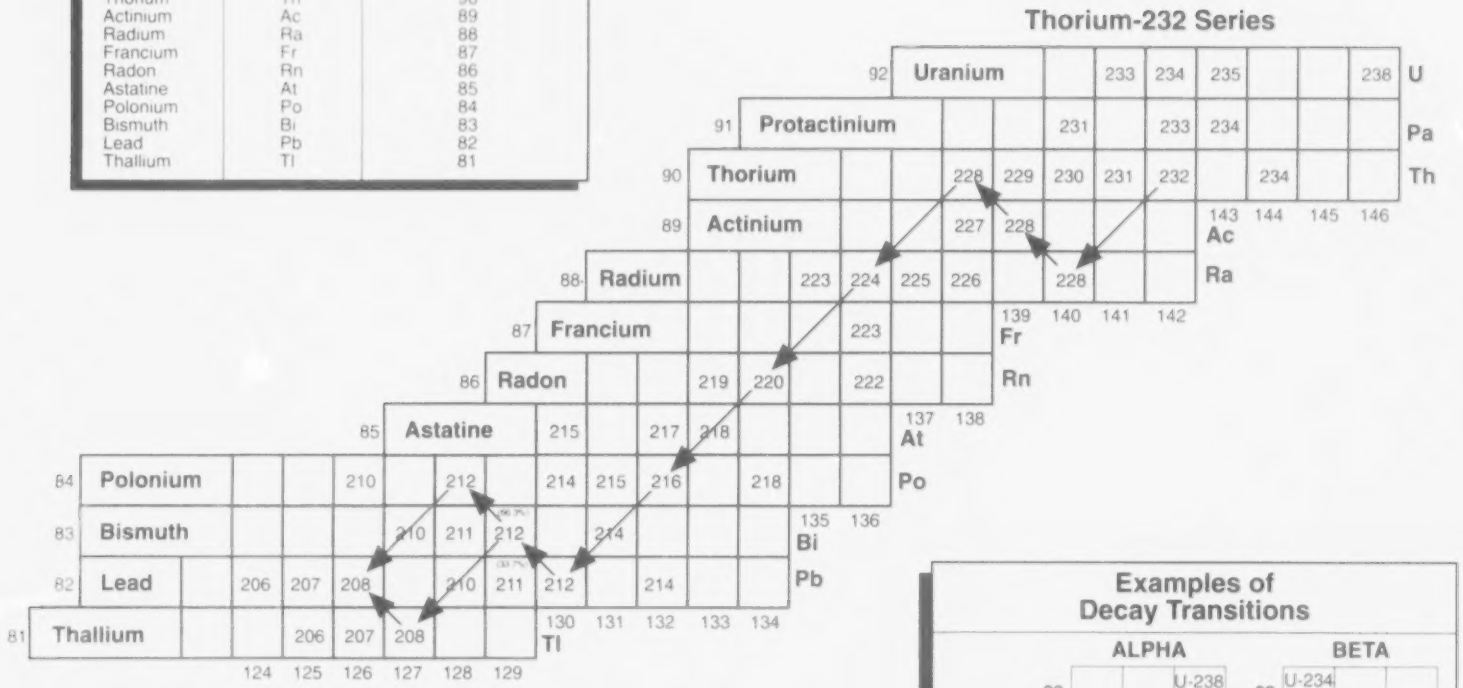
CHART OF THE ISOTOPES IN THE U-238, U-235, AND Th-232 DECAY SERIES

Element	Symbol	Number of Protons in Nucleus (Atomic Number)
Uranium	U	92
Protactinium	Pa	91
Thorium	Th	90
Actinium	Ac	89
Radium	Ra	88
Francium	Fr	87
Radon	Rn	86
Astatine	At	85
Polonium	Po	84
Bismuth	Bi	83
Lead	Pb	82
Thallium	Tl	81



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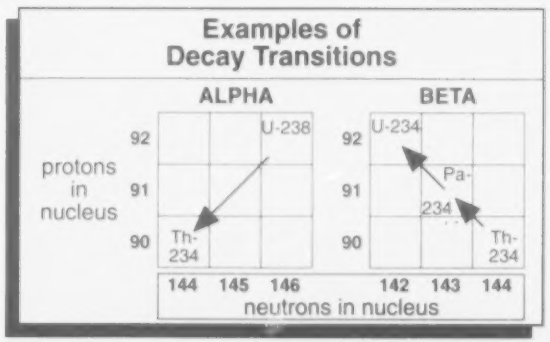

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Lead	Pb	82
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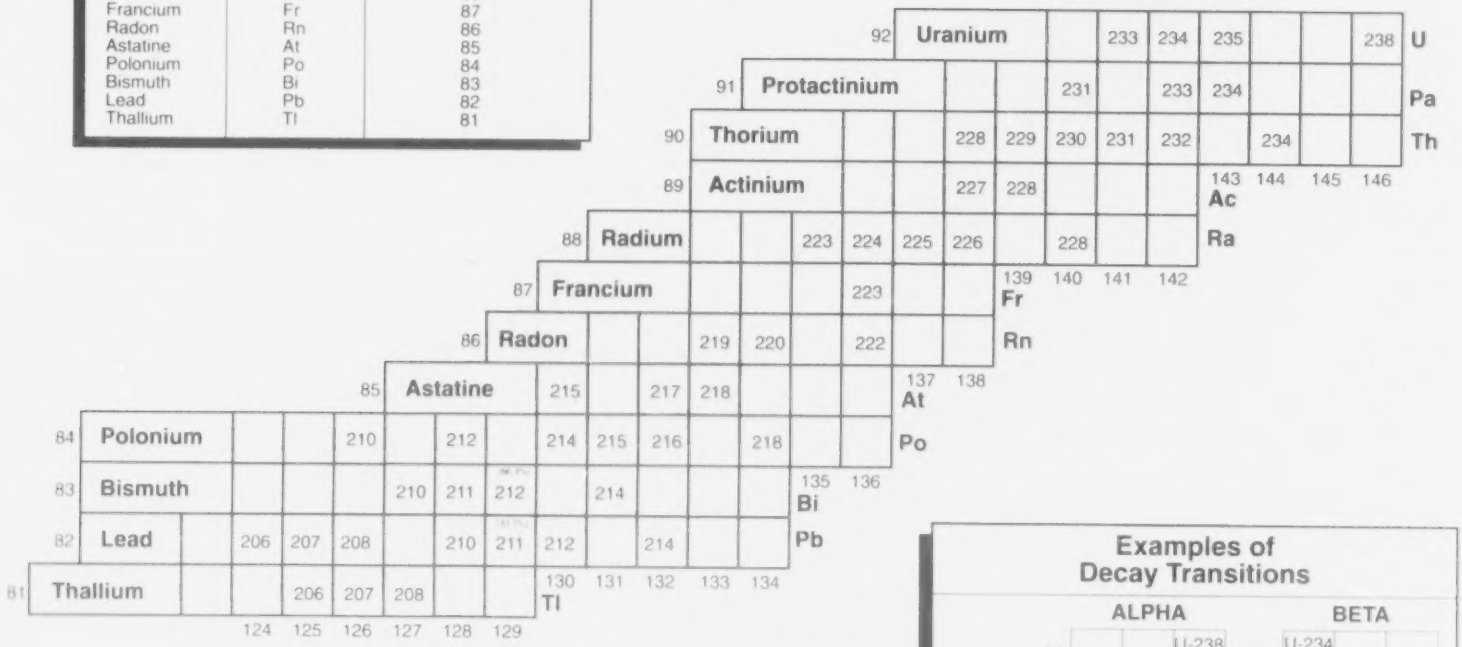
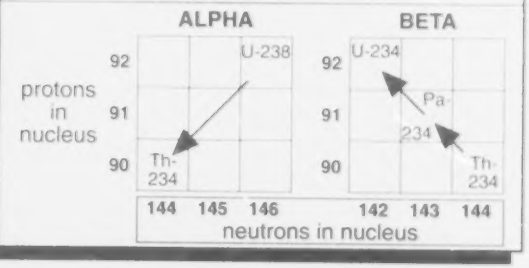
Uranium-235 Series



Examples of Decay Transitions



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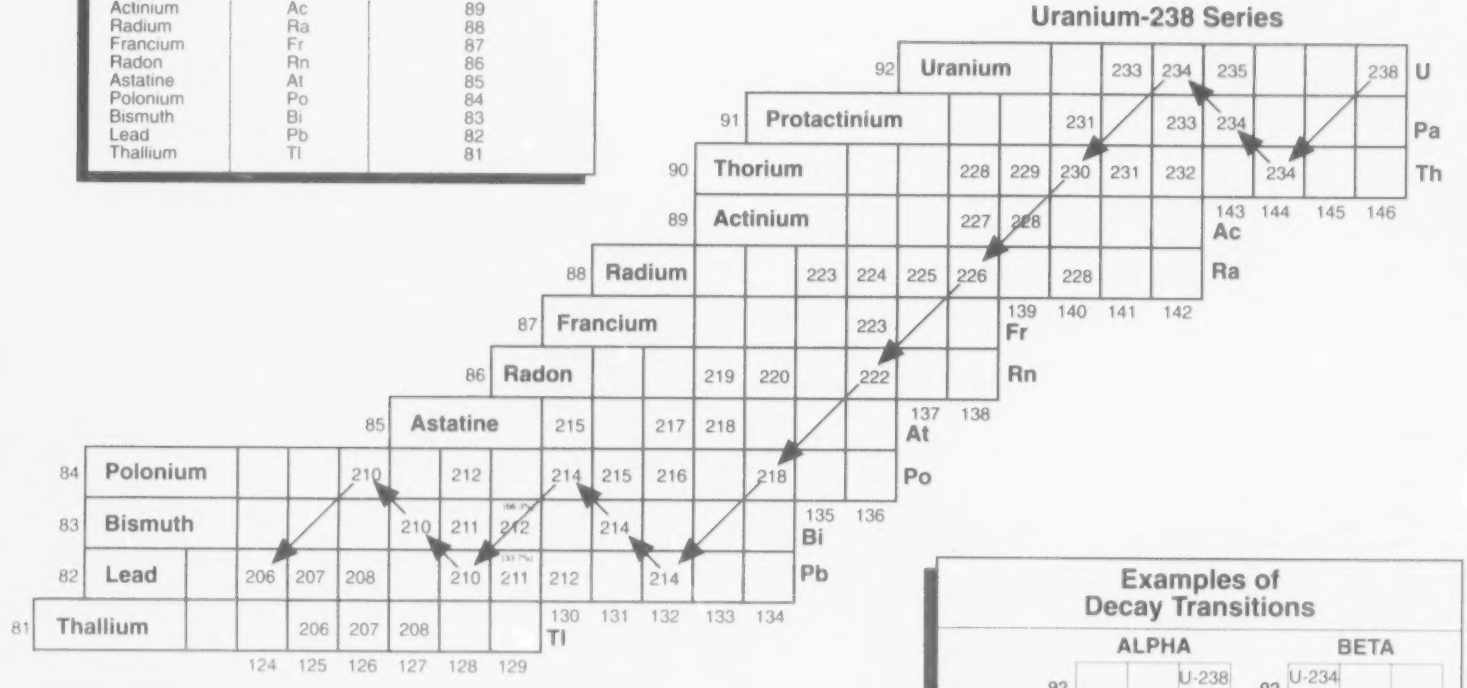

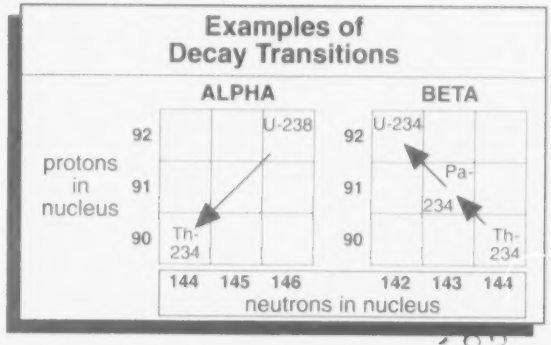

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TABLE OF SOME IMPORTANT ATOMIC TRANSITIONS IN SPENT FUEL

Directions: Using the information presented in the table below trace some important transitions in spent fuel on the Chart of Some Important Isotopes in Spent fuel.

Number of Protons in Nucleus (Atomic Number)	Isotope	Half-Life	Decay
94	Pu-241	13.2 years	Beta
95	Am-241	458 years	Alpha
93	Np-237	2,140,000 years	Alpha
91	Pa-233	27 days	Beta
92	U-233	162,000 years	Alpha
90	Th-229	7,340 years	Alpha
88	Ra-225	14.8 days	Beta
89	Ac-225	10.0 days	Alpha
87	Fr-221	4.8 minutes	Alpha
85	At-217	0.03 seconds	Alpha
83	Bi-213	47 minutes	98% Alpha 2% Beta
84	Po-213	0.0000042 seconds	Alpha
81	Tl-209	2.20 minutes	Beta
82	Pb-209	3.3 hours	beta
83	Bi-209	Stable	Stable

CHART OF SOME IMPORTANT ISOTOPES IN SPENT FUEL

Element	Symbol	Number of Protons in Nucleus (Atomic Number)
Uranium	U	92
Protactinium	Pa	91
Thorium	Th	90
Actinium	Ac	89
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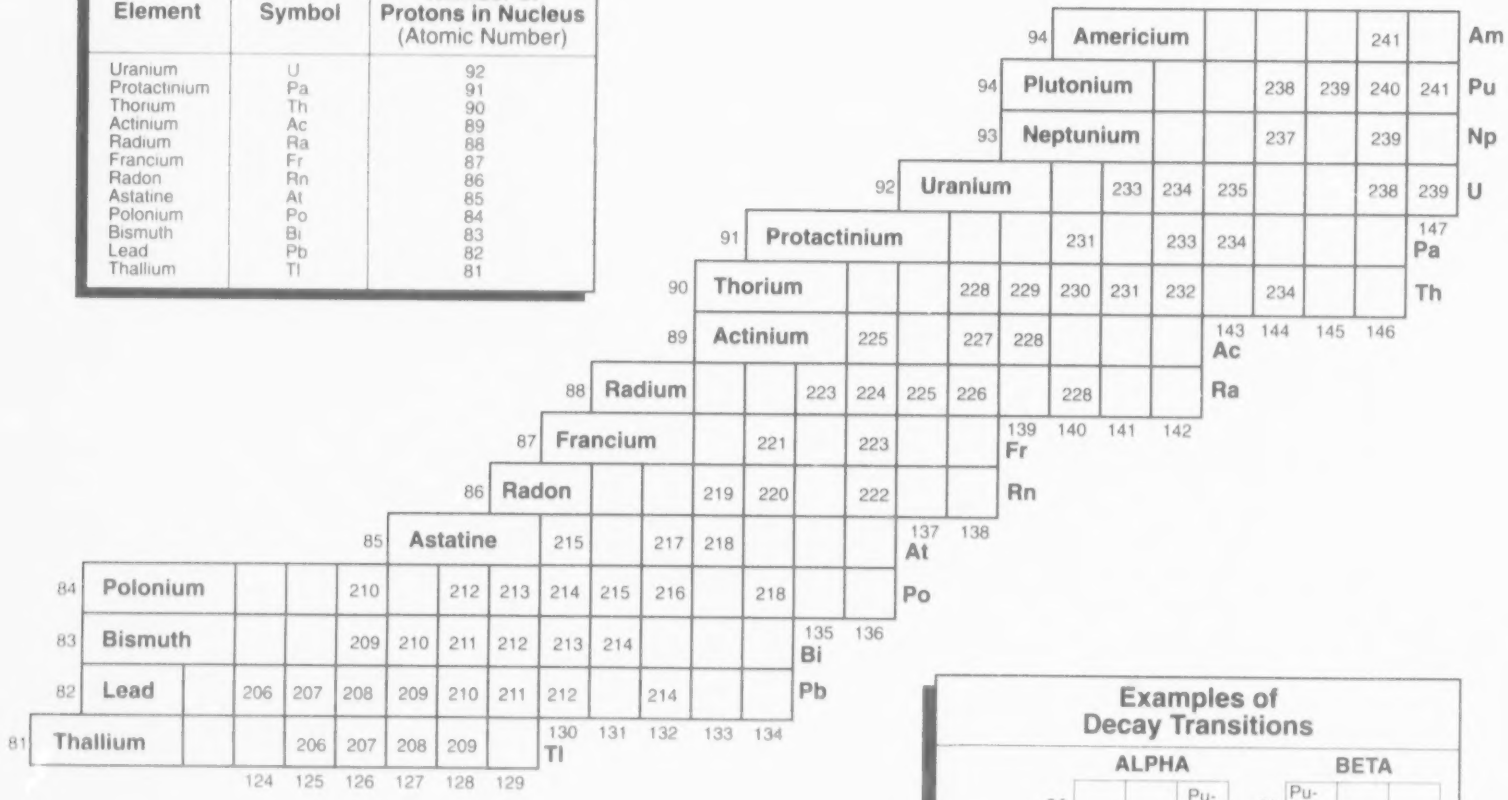
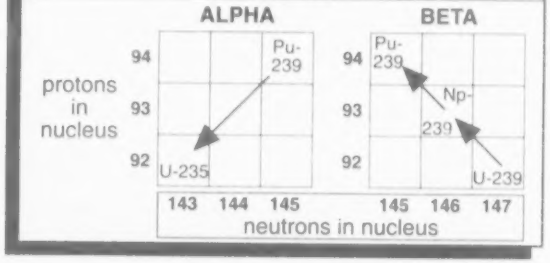


Adapted from The Chart of the Nuclides, Knolls Atomic Power Laboratory, Schenectady, New York, Operated by General Electric Company for Naval Reactors, the United States Department of Energy.

Examples of Decay Transitions



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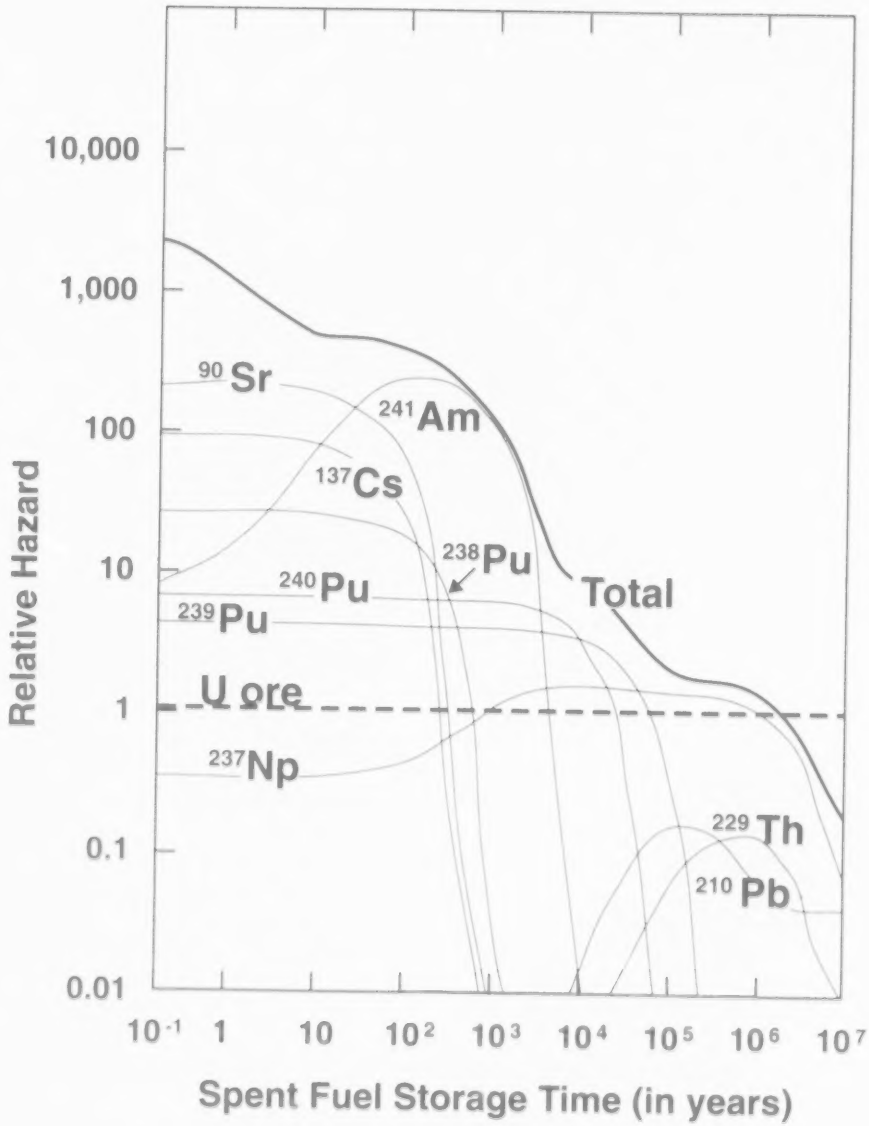
HAZARDS OF SOME ISOTOPES IN SPENT FUEL COMPARED TO THE HAZARD OF URANIUM ORE



HAZARDS OF SOME ISOTOPES IN SPENT FUEL COMPARED TO THE HAZARD OF URANIUM ORE

Directions: Use the graph entitled *Hazards of Some Isotopes in Spent Fuel Compared to the Hazard of Uranium Ore* to answer the questions below.

Part I

1. Identify the isotopes. (If necessary, refer to the periodic table of the elements.)

^{90}Sr	_____	^{241}Am	_____	^{137}Cs	_____
^{238}Pu	_____	^{240}Pu	_____	^{241}Pu	_____
^{237}Np	_____	^{229}Th	_____	^{210}Pb	_____

2. Identify the information on each axis.

X axis (horizontal):

The x axis uses a logarithmic scale (exponential notation) to represent the years of spent fuel storage. How many years are represented by each of the following:

10^{-1} _____ 1 _____ 10 _____ 10^{2} _____ 10^{3} _____

10^{4} _____ 10^{5} _____ 10^{6} _____ 10^{7} _____

Y axis (vertical):

Relative hazard is one of many ways to compare the potential hazards of radioactive elements. The y axis measures the "relative hazard" of each isotope compared to the hazard of uranium ore, which is naturally radioactive. Although all the isotopes in spent fuel are not shown, the hazard from all isotopes present in spent fuel, considered as a whole, is shown as "Total."

Like the x axis, the y axis is a logarithmic scale. From the relative hazard list given below, insert the correct term in sentences a-f.

one tenth	one hundredth	ten times
one hundred times	one thousand times	ten thousand times

a. A substance located at 0.01 represents _____ the hazard of uranium ore.

b. A substance located at 0.1 represents _____ the hazard of uranium ore.

c. A substance located at 10 represents _____ the hazard of uranium ore.

d. A substance located at 100 represents _____ the hazard of uranium ore.

e. A substance located at 1,000 represents _____ the hazard of uranium ore.

f. A substance located at 10,000 represents _____ the hazard of uranium ore.

Part II

1. When spent fuel is first placed in storage, what is the hazard of the isotopes in the spent fuel in comparison to the hazard of uranium ore?

Sr-90 between _____ and _____ times (more? less?) hazardous than uranium ore

Cs-137 between _____ and _____ times (more? less?) hazardous than uranium ore

Pu-238 between _____ and _____ times (more? less?) hazardous than uranium ore

Am-241 between _____ and _____ times (more? less?) hazardous than uranium ore

Pu-240 between _____ and _____ times (more? less?) hazardous than uranium ore

Pu-239 between _____ and _____ times (more? less?) hazardous than uranium ore

Np-237 between _____ and _____ times (more? less?) hazardous than uranium ore

2. Between what years does each of the following isotopes reach the level of hazard of uranium ore? (The first answer is done as an example.)

Element	Storage Time (Exponential Notation)	Storage Time (Years)
Sr-90	Between 10^2 and 10^3 years	Between 100 and 1,000
Am-241		
Cs-137		
Pu-238		
Pu-239		
Pu-240		
Np-237 (first)		
Np-237 (second)		

Between what years does the hazard of the spent fuel considered as a whole reach the level of hazard of uranium ore?

Total _____ _____

3. Does the relative hazard for an isotope decrease over the long term? Explain.

4. Does the relative hazard for an isotope always decrease over shorter time periods? Explain your answer.

5. When the spent fuel is first placed in storage, the relative hazard of neptunium-237 is (less?) than that of uranium ore. After 10^3 years, the hazard has (increased?). Then at about 10^6 years, it (decreases?) to that of uranium ore and continues to (decrease?). Explain how this is possible.

6. Look at the graphs of relative hazard for Th-229 and Pb-210. Notice that their graphs do not even begin until approximately 10,000 years. Where do you think these isotopes come from? How hazardous are they compared to uranium-238?

7. In the graph, the hazard for uranium ore is shown as a constant for comparative purposes. In reality, the hazard for uranium changes over time. Do you think the hazard for uranium would increase or decrease over time? Why?

8. The canister in which spent fuel will be stored is being designed to provide isolation for a minimum of 300 years. The repository itself must provide isolation of spent fuel from the accessible environment for 10,000 years. Using the information in the graph, explain why 300 years and 10,000 years are reasonable periods of time.

Part III

1. The period of time represented on the x axis is very long. To get some perspective of exactly how long, a timeline is shown below that goes back in time. Put the following items on the timeline in the appropriate place by making a tick mark and labeling it. The first item is done as an example. (If necessary, refer back to Part I for the conversions from exponential notations.)

   a. Average lifespan of US citizen—70-72 years

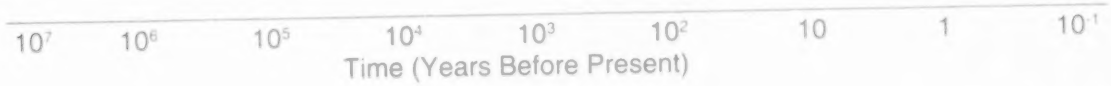
   b. The oldest known living plant (in 1990), a bristle cone pine, which is growing in the Sierra Nevada Mountain sprouts in the area of the Nevada/California border—4,900 years ago

   c. End of last Ice Age—10,000 years ago

   d. Meteor strikes Arizona and creates Meteor Crater—150,000 years ago

   e. Beginning of last Ice Age—2,500,000 years ago

   f. Earliest primate hominid remains deposited—5,000,000 years ago



2. Despite the length of time represented above, it is not very long in comparison to time spans used to describe the whole history of the Earth. To illustrate this point, several other important dates that geologists have established are given below. What are those dates in years?

   a. Years since the last dinosaurs died: $6.5 \times 10^7 =$ _____

   b. Years since the formation of the Earth: $4.6 \times 10^9 =$ _____

   c. How many years elapsed between the formation of the Earth and the end of the dinosaurs?

   _____

   d. How many years elapsed between the formation of the Earth and the beginning of the last Ice Age? _____

   e. How many years elapsed between the end of the dinosaurs and the beginning of the last Ice Age? _____

Across the top of the graph entitled "Relative Hazard of Some Isotopes in Spent Fuel Compared to Hazard of Uranium Ore" are tick marks. Label them to match the timeline for time before the present. Then add points along the top to represent the correct location for items a through f in question 1. This will help you to understand the length of time for storage of spent fuel that is represented by the graph.

Then answer the questions on the next page.

3. Suppose you live in St. Louis and have a time machine and decide to check the figures on this graph. You travel back in time 10^4 years ago. Would you need to take a coat? Why or why not?

4. Then you travel into the future. After 5,100 years of travel, a little longer than the length of time the bristle cone pine has lived, you stop to think about the spent fuel in storage.

   a. What is the relative hazard of strontium-90 when you check it compared to what its hazard was in the present?

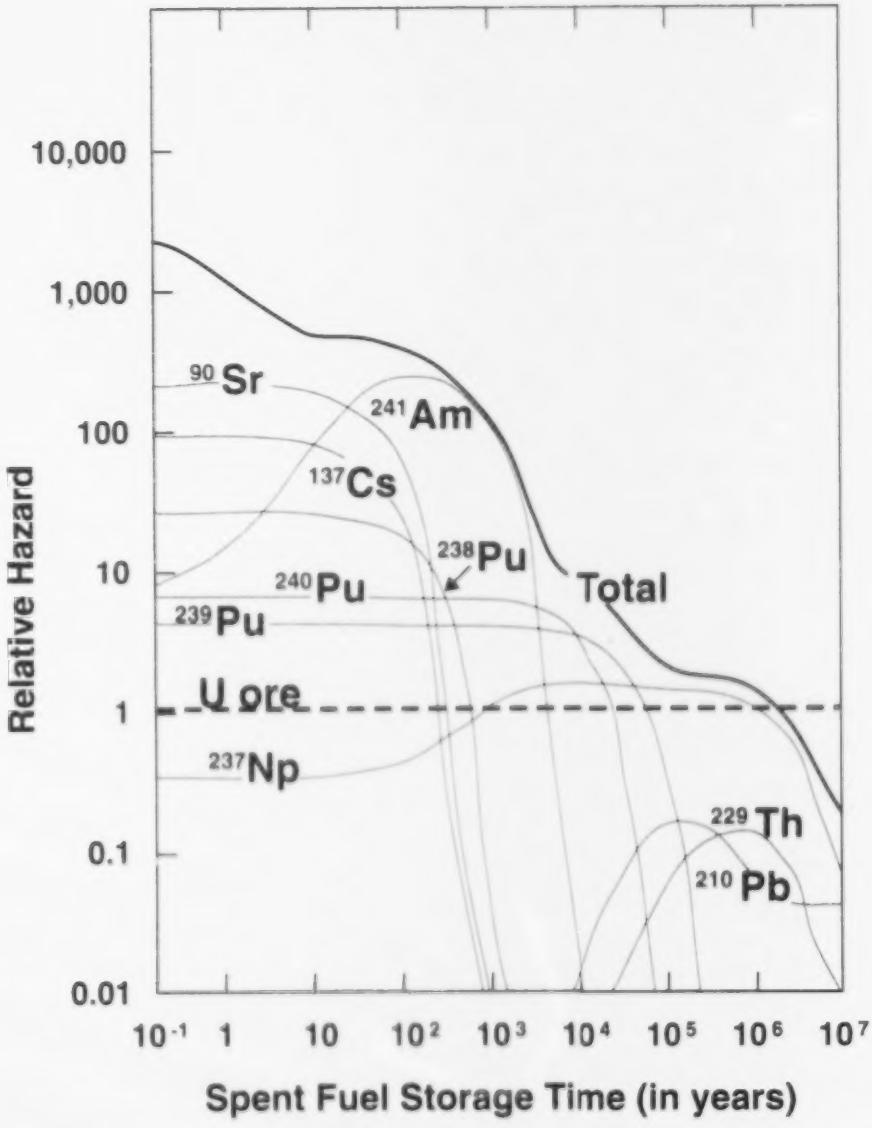
   b. What is the relative hazard of Americium-241 in comparison to the hazard of uranium ore? Has the relative hazard changed at all during the 5,100 years? Why or why not?

   c. At 5,100 years, what isotopes are still more hazardous than the standard for uranium ore? (Use abbreviations.)

   d. How does the hazard of all the isotopes considered as a whole (i.e., Total) compare to the hazard of uranium ore?

   e. Why are the decay rates shown important in planning for disposal of spent fuel?

HAZARDS OF SOME ISOTOPES IN SPENT FUEL COMPARED TO THE HAZARD OF URANIUM ORE



METRIC AND U.S. UNIT CONVERSIONS

Both American and metric units have been used in the curriculum, as appropriate to the issues being discussed. For example, inventories of spent fuel are routinely reported in the United States in terms of metric tons (1,000 kilograms) even though most Americans are familiar with the short ton (2,000 pounds). Classroom experiments are usually conducted using metric units as well. Yet the standards and tests for spent fuel transportation casks are written using temperature in degrees Fahrenheit, miles per hour, and other similar units.

To familiarize yourself with potentially unfamiliar metric units, a conversion chart has been prepared. To convert a given unit into its metric or U.S. equivalent, multiply the quantity by the number in the right hand column. For example, to convert 1,000 kilograms into its equivalent in pounds, multiply by 2.205 to get 2,205 pounds (1,000 kg x 2,205 lb/kg = 2,205 lb). Alternately, 2,000 pounds is equivalent to 2,000 lb x 0.4536 kg/lb or 907.2 kilograms.

People vary in their comprehension of metric units and unfamiliar U.S. units. Consider using this chart as an aid if you are confused or if you are especially interested in unit conversions.

Table 1. Approximate Conversions from Metric to English Units

If you know...

Length →	multiply by →	to get
millimeters (mm)	0.03937	inches (in)
centimeters (cm)	0.03281	feet (ft)
centimeters (cm)	0.3937	inches (in)
meters (m)	39.37	inches (in)
meters (m)	3.281	feet (ft)
meters (m)	1.094	yards (yd)
kilometers (km)	3,281.0	feet (ft)
kilometers (km)	0.5396	nautical miles (mi)
kilometers (km)	0.6214	statute miles (mi)
Area		
hectares (ha)	2.471	acres
hectares (ha)	1.076 X 105	square ft (ft^2)
Weight (mass)		
grams (gm)	0.03527	ounces (oz)
grams (gm)	0.002205	pounds (lb)
kilograms (kg)	2.205	pounds (lb)
metric tons (t)	1.102	short tons
metric tons (t)	0.984	long tons
Pressure		
kilopascals (kPa)	6.9	pounds/square inch (lb/in^2)
Volume		
cubic centimeters (cm^3)	0.06202	cubic inches (in^3)
cubic meters (m^3)	3.531	cubic feet (ft^3)
cubic meters (m^3)	1.307	cubic yards (yd^3)
liters (L)	2.113	pints* (pt)
liters(L)	0.2642	gallons* (gal)
Temperature		
Celsius	9/5, [then add 32]	Fahrenheit
Electric Current		
ampere (A)	1	ampere (A)
Energy, Work, Heat		
joule (J)	9.480×10^{-4}	BTU
Power		
watt (W)	1	watt (W)
watt (W)	3.4129	BTU per hour
watt (W)	1.341×10^{-3}	horsepower

Common Prefixes for Metric Units:

mega = million = 10^6	deci = one-tenth
kilo = thousand	centi = one-hundredth
hecto = hundred	milli = one-thousandth
deka = ten	micro = one-millionth
Examples:	kilogram = 1,000 grams
	milliliter = 1/1,000 liter

*liquid measure

Table 2. Approximate Conversions from English to Metric Units

If you know...

Length →	multiply by →	to get
inches (in)	2.54	centimeters (cm)
feet (ft)	30.48	centimeters (cm)
feet (ft)	0.3048	meters (m)
miles (mi)	1.609	kilometers (km)
yards (yd)	0.9144	meters (m)
Area		
square inches (in^2)	6.5	square centimeters (cm^2)
square feet (ft^2)	0.09	square meters (m^2)
square yards (yd^2)	0.8	square meters (m^2)
acres	0.4047	hectares (ha)
square miles (mi^2)	2.6	square kilometers (k^2)
Weight (mass)		
ounces (oz)	28.349527	grams (gm)
pounds (lb)	0.4536	kilograms (kg)
tons (long)	1.016	metric ton (t)
Pressure		
pounds per square inch	70.31	grams per square centimeter
pounds per square inch	0.145	kilopascals
Volume		
cubic feet (ft^3)	0.02832	cubic meters (m^3)
cubic inches (in^3)	16.387	cubic centimeters (cm^3)
cubic yards (yd^3)	0.765	cubic meters (m^3)
gallons* (gal)	3.785	liters (L)
pints* (pt)	0.473	liters (L)
quarts* (qt)	0.946	liters (L)
Temperature		
Fahrenheit	[subtract 32, then multiply by 5/9]	Celsius
Electric Current		
ampere (A)	1	ampere (A)
Energy, Work, Heat		
BTU	1,055	joules (J)
Power		
watt (W)	1	watt (W)
BTU per hour	0.293	watt (W)
horsepower	745.712	watt (W)

*liquid measure

TEST

NAME: _____

Directions: Circle the letter of the answer that best completes the statement given:

1. Ionizing radiation is called "ionizing" because:

   a. it is emitted by charged particles called ions.
   b. it is everywhere.
   c. we can detect it with our senses.
   d. it produces charged particles called ions in materials it penetrates.

2. Some important forms of ionizing radiation are:

   a. high-frequency sound waves.
   b. gamma rays and X-rays.
   c. microwaves and radar.
   d. ultraviolet light from grow lamps.

3. An important form of non-ionizing radiation is:

   a. gamma ray.
   b. visible light.
   c. X-ray particle.
   d. beta particle.

4. The least penetrating form of ionizing radiation is:

   a. alpha particles.
   b. beta particles.
   c. gamma rays.
   d. electrons.

5. The highest deposit energy per unit path in human tissue is from:

   a. alpha particles.
   b. beta particles.
   c. X-rays.
   d. gamma rays.

6. A given exposure to gamma rays will have the least effect if it is received:

   a. all at once.
   b. in two exposures a few minutes apart.
   c. in several exposures over a period of hours.
   d. in several exposures over a period of weeks or months.

7. The spontaneous emission of fast-moving particles and rays by an atom is called:

   a. atomization.
   b. spontaneous combustion.
   c. current emissions.
   d. radioactivity.

8. .Isotopes that spontaneously emit ionizing radiation are often called:

   a. radiators.
   b. radiation.
   c. radioisotopes.
   d. radio transmitters.

9. For people living in the United States, the average annual exposure to ionizing radiation from all sources is:

   a. 20 millirem.
   b. 55 millirem.
   c. 360 millirem.
   d. 500 millirem.

10. The average U.S. resident receives the highest percent of exposure to ionizing radiation from:

    a. medical diagnosis and treatment.
    b. nuclear powerplants and nuclear waste.
    c. transportation of nuclear materials.
    d. natural sources (rocks, soil, cosmic radiation, radon).

11. If your family found an unacceptable amount of radon present in your home, the best way to control exposure would be:

    a. move away.
    b. close all the doors and windows.
    c. improve your home's ventilation.
    d. install a humidifier in your basement.

12. Two isotopes present in the food we eat that contribute to our internal radiation exposure are:

    a. potassium-40 and carbon-14.
    b. tritium-234 and radon-222.
    c. uranium-234 and thorium-230.
    d. iodine-131 and cesium-137.

13. The half-life of a radioactive isotope is the time in which:

    a. single radioactive atom loses half its radioactivity.
    b. a quantity of a radioactive substance loses half its radioactivity.
    c. a quantity of a radioactive substance loses half its mass.
    d. a nucleus is divided in half.

14. The half-life of a radioactive isotope is the time in which it has a _____ chance of decaying.

    a. 25%
    b. 50%
    c. 75%
    d. 100%

15. People can achieve protection from exposure to radiation by:

    a. increasing length of time of exposure.
    b. decreasing distance from the source.
    c. increasing shielding.
    d. decreasing shielding.

16. Which of the following best represents a gamma ray?

    a.
    b.
    c.
    d.

17. We assume that there is some risk even for low exposures to ionizing radiation because:

    a. there are a lot of data that show that there is an effect.
    b. we cannot prove that there is no effect.
    c. no other substances cause similar effects.
    d. effects of high exposures prove effects at low exposures.

18. Which of the following does **NOT** travel at the speed of light?

    a. beta particle.
    b. radar.
    c. visible light.
    d. radio wave.

19. There is general agreement among scientists about the effects on the body from:

    a. both high and low exposures to ionizing radiation.
    b. neither high nor low exposures to ionizing radiation.
    c. high exposures to ionizing radiation received in a short time.
    d. low exposures to ionizing radiation received over a long time.

20. The process in which an atom emits particles and is transformed into a different element is:

    a. spontaneous decay.
    b. random decay.
    c. transformation.
    d. radioactive decay.

1. D
2. B
3. B
4. A
5. A
6. D
7. D
8. C
9. C
10. D
11. C
12. A
13. B
14. B
15. C
16. D
17. B
18. A
19. C
20. D

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